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COMPUTER SIMULATION OF AN ELECTRIC TROLLEY BUS

John J. Stickler

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
Transportation Systems Center
Cambridge MA 02142

DECEMBER 1979

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Earlier reports that describe the simulation models of different types of bus propulsion systems include: "Flywheel/Diesel Hybrid Power Drive: Urban Bus Vehicle Simulation" (PB 294-778); "Diesel Bus Performance Simulation Program" (PB 295-524); and "Simulation of an Urban Battery Bus" (PB 300-306).

16. Abstract

This report describes a computer model developed at the Transportation Systems Center (TSC) to simulate power/propulsion characteristics of an urban trolley bus. The work conducted in this area is sponsored by the Urban Mass Transportation Administration as part of a larger effort concerned with the demonstration and test evaluation of advanced bus propulsion concepts. The computer models developed by TSC provide a means of rapidly evaluating bus performance and of comparing simulated bus performance with results obtained from engineering tests. They also provide a means of developing comparative information of the performance characteristics and component sizing requirements of various bus propulsion systems. The results of the computer analyses will be incorporated into the Annual Technological Assessment Report for future reference and evaluation. This present report includes a description of the application of the trolley bus model to a typical urban bus drive cycle. The requested mission profile is given as input to the bus model while the actual mission profile determined by the limitation of the bus propulsion system appears as output. The output data file also lists the electrical drive characteristics, including component power losses, at successive intervals of drive time. The report describes the computer simulation of an electric trolley bus as it traverses an arbitrary mission profile of specified acceleration, roadway grade, and headwind. The models for the different bus components are examined and the impact of cam-control on trolley bus performance is reviewed. The simulation model is used to generate power-propulsion characteristics for a trolley bus operating over different urban drive cycles. Program listings, including a CALCOMP subroutine for graphic display, are presented in the Appendix.

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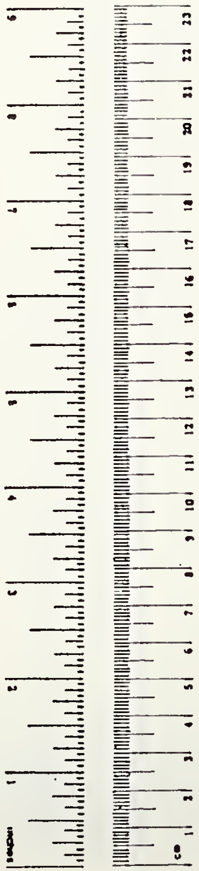
PREFACE

This report describes a computer model of an electric trolley bus developed at the Transportation Systems Center to simulate the power/propulsion characteristics of an urban trolley bus. This model comprises the fourth in a series of models being developed at TSC to simulate different types of bus propulsion systems. Earlier reports describing these models include: 1) "Flywheel/Diesel Hybrid Power Drive: Urban Bus Simulation," DOT-TSC-78-10, UMTA-MA-06-0044-78-1, Final Report, May 1978; 2) "Diesel Bus Performance Simulation Program," DOT-TSC-UMTA-79-16, UMTA-MA-06-0044-79-1, Final Report, April 1979; and 3) "Simulation of an Urban Battery Bus," DOT-TSC-UMTA-79-15, UMTA-MA-06-0093-79-1, Final Report, July 1979. These simulation models provide the capability for rapid evaluation of bus performance through the comparison of simulated bus performance with data obtained from engineering tests. The work conducted in this area is sponsored by the Urban Mass Transportation Administration and is part of a larger effort concerned with the demonstration and test evaluation of advanced bus propulsion concepts.

METRIC CONVERSION FACTORS

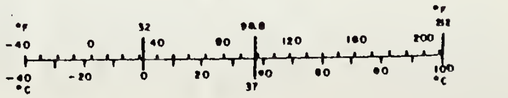
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

This report describes a computer model developed at the Transportation Systems Center to simulate power/propulsion characteristics of an urban trolley bus. This model comprises the fourth in a series of models being developed at TSC to simulate different types of bus propulsion systems. The work conducted in this area is sponsored by the Urban Mass Transportation Administration as part of a larger effort concerned with the demonstration and test evaluation of advanced bus propulsion concepts. The computer models developed by TSC provide a means of rapidly evaluating bus performance and of comparing simulated bus performance with results obtained from engineering tests. They also provide a means of developing comparative information on the performance characteristics and component sizing requirements of various bus propulsion systems. The results of the computer analyses will be incorporated into the Annual Technological Assessment Report for future reference and evaluation.

This report includes a description of the application of the trolley bus model to a typical urban bus drive cycle. The requested mission profile is given as input to the bus model while the actual mission profile determined by the limitation of the bus propulsion system appears as output data. The output data file also lists the electrical drive characteristics, including component power losses, at successive intervals of drive time. Applications of the trolley bus model anticipated for the future include the evaluation of energy consumption, the impact of component sizing on bus operation, and the effect of mission profile on the ultimate efficiency of the trolley bus. Studies of this type provide a useful data base for assessing the capabilities of the bus propulsion system in urban transit applications.

1. INTRODUCTION

This report describes a computer model of the propulsion system of an electric trolley bus and the application of this model for simulating trolley bus performance. The computer model has been implemented on the DECsystem-10 computer located at the Transportation Systems Center (TSC) in Cambridge, Massachusetts. Written in FORTRAN-10 source language, the program could be run on most large-scale computer systems.

The program models an electric-powered passenger vehicle traversing a defined mission profile of acceleration, cruising speed, roadway grade, and encountered headwind. Sufficient flexibility has been introduced into the system (Model) to allow for arbitrary mission profiles and variations in the system component specifications. The program has been designed to evaluate the power consumption of a trolley bus under varied conditions of operation, including the use of regeneration for optimum power utilization.

The computer simulation of the electric trolley bus has several objectives. First, it offers a convenient means of assessing the performance capabilities of an electric trolley bus and of comparing its performance with that of other electric and non-electric vehicles. Such comparisons are useful for evaluating the relative merits of different vehicle propulsion systems. The conditions under which one system can be optimized relative to another system are easily explored via computer models. Second, the computer simulation affords a means of examining the impact of a particular speed-time profile on trolley bus performance. The choice of one transit profile over another can be made using the computer program to estimate energy losses under varying profile conditions. The effect of power regeneration on overall vehicle efficiency as well as the best choice of power control equipment for optimum vehicle performance can also be easily assessed using computer simulation techniques.

The purpose of this report is to document the electric trolley bus program and to provide the reader with the necessary information to operate the program and to interpret the results obtained from its use. Detailed procedures are given in the form of a user's guide for executing the program on a DECsystem-10 computer. These are summarized in Section 3.2 of the report. Section 5 contains FORTRAN source listings of the main program and all subroutines as well as sample output data. As a guide for understanding the model and interpreting the computer results, the modeling theory and equations are detailed in Section 4.

1.1 MODULAR PROGRAM FORMAT

The computer model utilizes a modular program format in which functions common to a given system component are contained in a separate subroutine. For example, all operations involving the generation of tractive effort and flow of power to and from the traction machine are delegated to the subroutine MOTOR. The advantage of this format is that it facilitates the interchange of alternative types of system components without impairing the basic integrity of the overall program. This is particularly useful when one wishes to explore the effect of changing the design parameters of a system component or to examine the effect of a particular mode of operation on the propulsion performance. This format has been utilized in previous modeling efforts (e.g., battery bus, AGRT systems) with favorable results.

Figure 1 shows a block diagram of the modular format as applied to the electric trolley bus. The separate subroutines which perform specific functions are PROFILE, PCU, and MOTOR. The MAIN program provides the calling statements and sequence logic necessary to maintain program continuity.

1.2 TROLLEY BUS: RESEARCH CONTEXT

The renewed interest in electric trolley vehicles has been stimulated by several factors. These rubber-tired transit vehicles are quiet, waste little energy at idle, and emit no exhaust fumes.

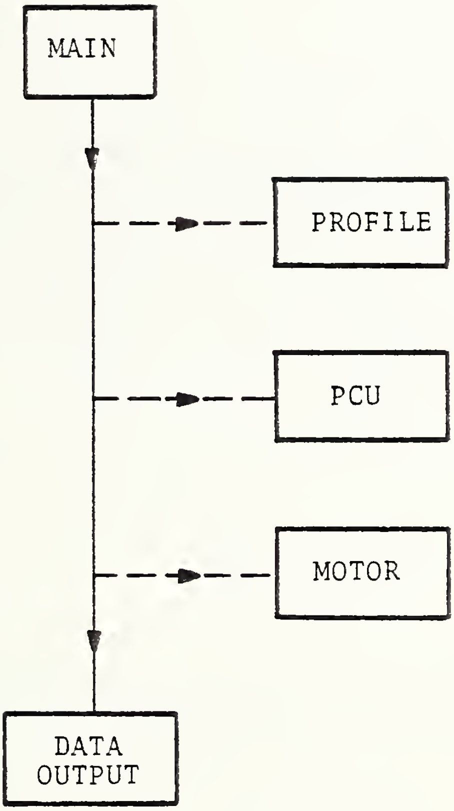


FIGURE 1. SKETCH OF MODULAR PROGRAM FORMAT

They are, therefore, well adapted to the great majority of urban driving environments. Because of the possibility of built-in storage devices, they have the flexibility of operating for certain distances off-wire.

Electric vehicles possess better acceleration characteristics, even under load, than do internal combustion vehicles. Consequently, they are capable of doing more work in a given time period compared with other vehicles. Furthermore, because of the scarcity and increasing costs of petroleum-based fuels, alternative forms of energy propulsion systems are becoming increasingly more attractive. Since the supply of fossil fuels far exceeds that of petroleum-based fuels, vehicles powered by electricity generated from fossil fuels are becoming more promising for the future.

Programs concerned with the development of electric-powered vehicles are now under way in a number of transportation-oriented companies in the United States. These include among others, General Electric, Boeing, Garrett Airesearch, Vought, and Westinghouse. These programs involve the development of electric-drive vehicles ranging in size from small commuter cars to large mass transit buses. In addition, studies are now in progress to determine the practicality of battery-powered buses and supplementary energy storage schemes, including flywheels.

2. BASELINE SYSTEM: COMPONENTS AND MODES OF OPERATION

2.1 BASELINE SYSTEM

The baseline system comprises a 24,400 lb trolley coach (fully loaded) driven by a GE 1213, 123 hp DC traction motor. A 600 volt overhead trolley supplies power. An MRC (multiple relay) controller provides control of traction motor speed by means of accelerator and brake pedals on the floor. The propulsion system is capable of accelerating the coach at 3 mph/sec up to a speed of 17 mph and at reduced accelerations up to the peak vehicle speed of 49 mph. Vehicle deceleration is achieved through either regenerative or dynamic frictional braking.

2.2 CONFIGURATION OF MAJOR COMPONENTS

The major components of the Trolley-Bus Simulation include the vehicle coach, DC compound motor, MRC (cam) controller, and power source (catenary). A block diagram showing the system components is given in Figure 2. The important quantities associated with each component are indicated below the diagram.

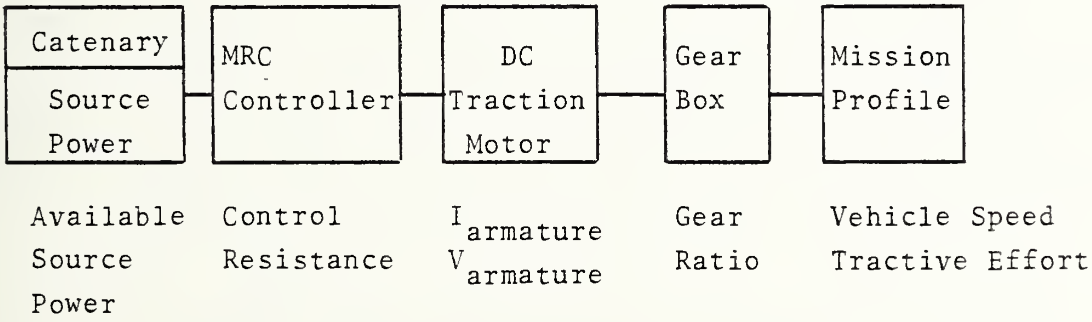


FIGURE 2. BLOCK DIAGRAM OF TROLLEY BUS SYSTEM

2.2.1 Trolley Coach

The trolley bus modeled in the computer program is a rubber-tired mass transit coach with a seating capacity of 15 passengers. Peak speed under normal operating conditions is 45 mph. Table 1 summarizes the coach parameters used in the computer model.

TABLE 1. TROLLEY COACH SPECIFICATIONS

Trolley Coach Specifications		
Curb Weight (WTCRB)	=	22,000 lb
Gross Weight (15 passengers)	=	24,400 lb
Frontal Area (AF)	=	69.5 ft^2
Aerodynamic Drag Coeff. (CD)	=	0.66
Rolling Drag Coeff. (CR)	=	.0075
Tire Factor (TF)	=	8.003
Gear Ratio (RATIO)	=	11.59 reduction
Wheel Diameter	=	42 in

2.2.2 Vehicle Mission Profile

The "mission" profile describes vehicle speed as a function of time. It can either be defined by a specified vehicle speed-time dependence or derived from input data on vehicle speed and acceleration (and deceleration). The latter approach is the one used in this simulation study.

Figure 3 shows one complete driving cycle of an arbitrary mission together with certain key mission profile parameters. The vehicle traverses a simulated bus route, which is defined by the number of stops per mile (NS) and the route length (SR). Multiple transits of the same route can also be run, with an optional waiting period added between routes (TAUMU). During this waiting period and whenever the vehicle is at rest, only the auxiliary loads (including environmental control systems) use power. The mission profile is further defined by the cruise speed between stops (VC), the required acceleration (ACCM) and deceleration (DECL), the encountered head wind (HW), and the roadway grade (GRADE). The stops are assumed to be equally spaced, and equal dwell time (DWELL) is spent at each stop for passenger boarding. This route model generates a repeating series of driving cycles between each stop as the vehicle traverses the mission.

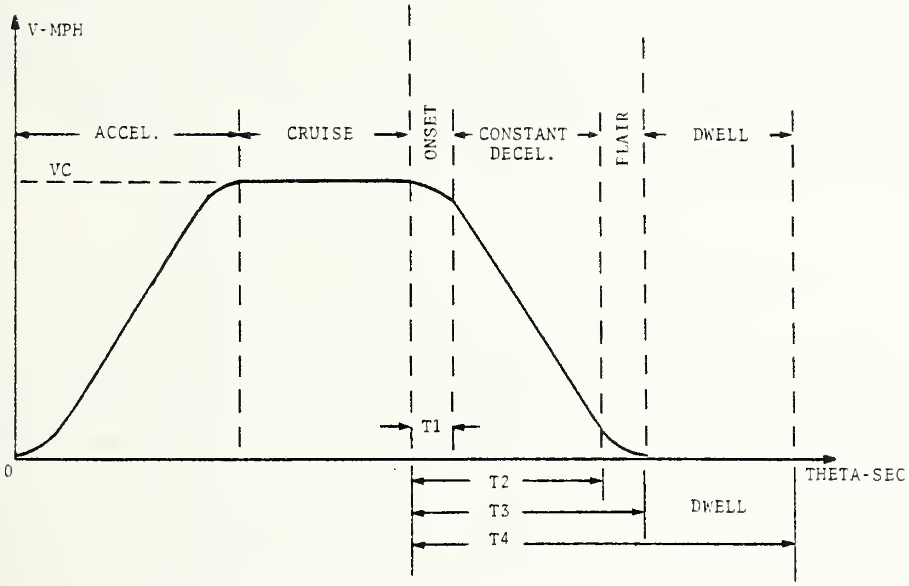


FIGURE 3. SPEED-TIME PROFILE FOR ONE CYCLE OF AN ARBITRARY MISSION

The mission profile is "specified" at the start of each computer run by selecting one of three programmed driving cycles, called cycles A, B, and C. The values of the different program constants associated with the A, B, and C drive cycles are given in Table 2. These drive cycles describe the vehicle speed and acceleration as "requested" by the bus operator. Actual vehicle speed and acceleration are determined by the available motor output power as well as by limitations in the control characteristics of the power control unit (PCU).

The vehicle starts from rest in a jerk-limited mode. (See Figure 3.) As the acceleration (ACC) increases to the required rate (ACCM), the jerk (AJERK) (which is the rate of change of acceleration) is constrained by a specified limit (AJERKR). As the vehicle approaches cruise speed (VC), a jerk-limited decrease of acceleration is programmed. At the proper speed, the vehicle acceleration is reduced to zero at the jerk-limited rate. During cruise, the controller (CAM) seeks to maintain constant cruise speed by alternately applying positive and negative tractive efforts. During deceleration, the vehicle undergoes a programmed deceleration profile in a reverse sequence to the acceleration profile. The vehicle is brought to rest with a specified deceleration (DECL).

TABLE 2. DRIVE CYCLE PARAMETER VALUES

Driving Cycle Data					
DESCRIPTION	FORTRAN SYMBOL	CYCLE A	CYCLE B	CYCLE C	UNITS
Thrust limited acceleration	ACCM	3.5	3.5	3.0	mph/sec
Deceleration rate	DECL	1.5	3.5	3.5	mph/sec
Cruise speed	VC	20.0	25.0	25.0	mph
Maximum allowed jerk	AJERKR	3.5	3.5	3.5	mph/sec^2
Number of stops per mile	NS	5	8	10	--
Distance between stops	SS	0.20	0.125	0.10	mi
Dwell time at each stop	DWELL	12.0	16.0	8.0	sec
Additional dwell at end of route	TAUMU	0.0	0.0	30.0	sec
Number of passengers	NP	20	10	15	--
Route length	SR	6.0	6.0	6.0	mi
Number of transits of route	NT	4	4	4	--
Armature current setpoint	SET	200.0	250.0	225.0	amp

2.2.3 DC Traction Motor

A GE 1213® compound wound, 150 hp, 600 volt DC traction motor is used in the trolley bus simulation. The electrical specifications of the motor are given in Table 3.

TABLE 3. DC MOTOR (GE 1213)® ELECTRICAL SPECIFICATIONS

Motor Electrical Specifications

Type: GE 1213 Compound Wound, Commutating Pole

No. of Poles = 4

Ratings:

Armature voltage = 600 vac
Armature voltage (AVE) = 550 vac
Armature current = 205 A
Shunt field current = 2.5 A
Output Power (Shaft) = 150 hp
Max. speed = 4500 rpm

Winding Data:

No. of shunt field turns = 1175
No. of series field turns = 12
Armature resistance = .0514Ω min., .0554Ω max.
Shunt field resistance = 80.5Ω min., 85.5Ω max.
Series field resistance = .0125Ω min., .0135Ω max.
Commutating resistance = .022Ω min., .030Ω max.

Additional information pertaining to the physical characteristics of the GE 1213 motor is given in Table 4.

TABLE 4. MOTOR (GE 1213) MECHANICAL SPECIFICATIONS

Weight:	
Motor (total)	1429 lb
Armature	395 lb
Armature Moment of Inertia	35 lb-ft^2
Max. Dynamic Braking Capability	2400 lb

Figure 4 shows the measured tractive effort (at wheels) and vehicle speed as a function of the DC armature current. Tractive force increases almost linearly with armature current for a given shunt field excitation. At vehicle speeds above 14 mph, it is necessary to reduce the shunt field excitation (field-weaken), as indicated in the figure.

Regenerative braking can be accomplished at higher speeds by increasing the motor field excitation sufficiently to cause the back EMF to exceed motor terminal voltage. The resulting braking effort (at the wheels) realized for different shunt field excitations is shown in Figure 5. Dynamic (rheostatic) braking can be accomplished over the full range of vehicle speeds by disconnecting the input power to the motor and connecting a suitable resistor grid across the armature terminals. Figure 5 shows the braking effort developed with a 1.5 ohm braking resistor and three different field excitations.

Magnetic saturation plays an important part in determining motor performance. Details regarding the manner in which magnetic saturation is included in the motor simulation are discussed in Section 4.2.

2.2.4 Power Controller (PCU)

Power to the DC motor is controlled by a type MRC controller which the vehicle operator activates by pushing down on the accelerator pedal. As the accelerator pedal is depressed, the controller cam assumes 1 of 14 different step positions. At each step position, a predetermined resistance is inserted into the armature and shunt field circuits. Table 5 lists the different 'cam' resistances and percent normal shunt field current for the various step positions. Inserting resistance into the armature circuit controls the motor terminal voltage, while inserting resistance into the shunt field circuit gives field (flux) control. Cam positions 1 through 10 give combined terminal voltage and field control; cam positions 10 through 14 yield field control.

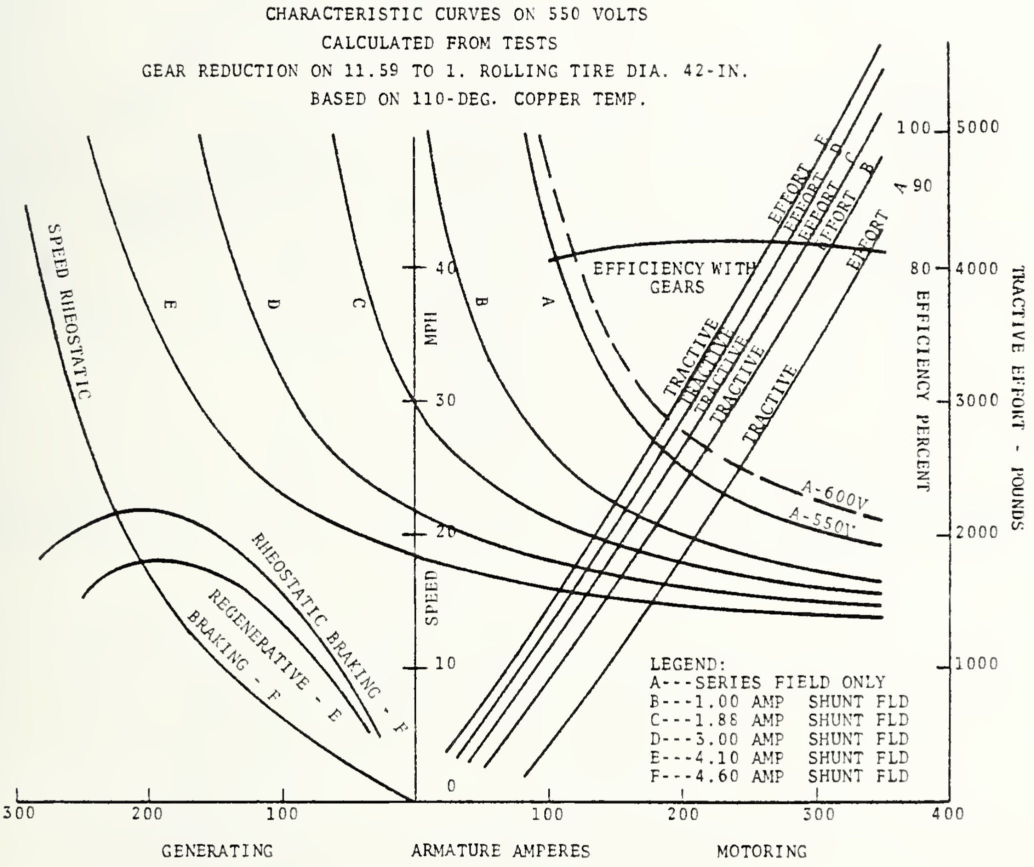


FIGURE 4. GE 1213® TRACTION MOTOR CHARACTERISTICS

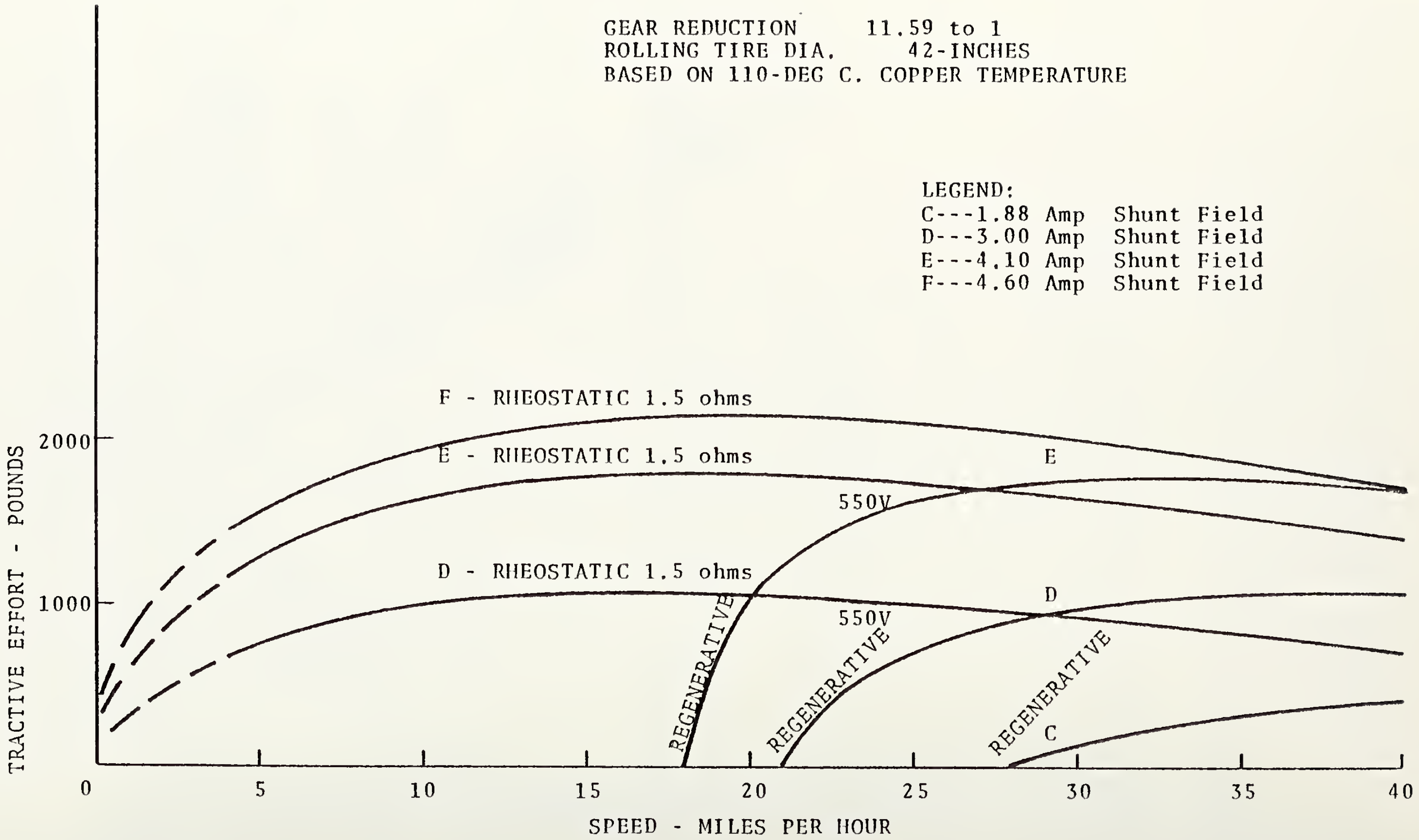


FIGURE 5. GE 1213® TRACTION MOTOR BRAKING CHARACTERISTICS

TABLE 5. MRC CONTROLLER RESISTANCE, CURRENT CHARACTERISTICS

Cam Position Accelerating	Percent of Total Series Resistance in Series with Motor	Percent Nor. Shunt Field Current	Approx. Bal. Speed MPH 550 Volts
	Open Circuit	0	
1	100	0	
2	100	26	
3	68	33	
4	50	100	
5	39	100	
6	27	100	
7	20	100	
8	12	100	
9	5	100	
10	0	100	17
11	0	72	20
12	0	46	24
13	0	24	30
14	0	0	40
Regen. Brake			
13 to 10 inc.	0	24 to 100%	40 to 17
Dynamic Braking			
1	52	73	
2	52	100	
3	52	112	
4*	52	112	

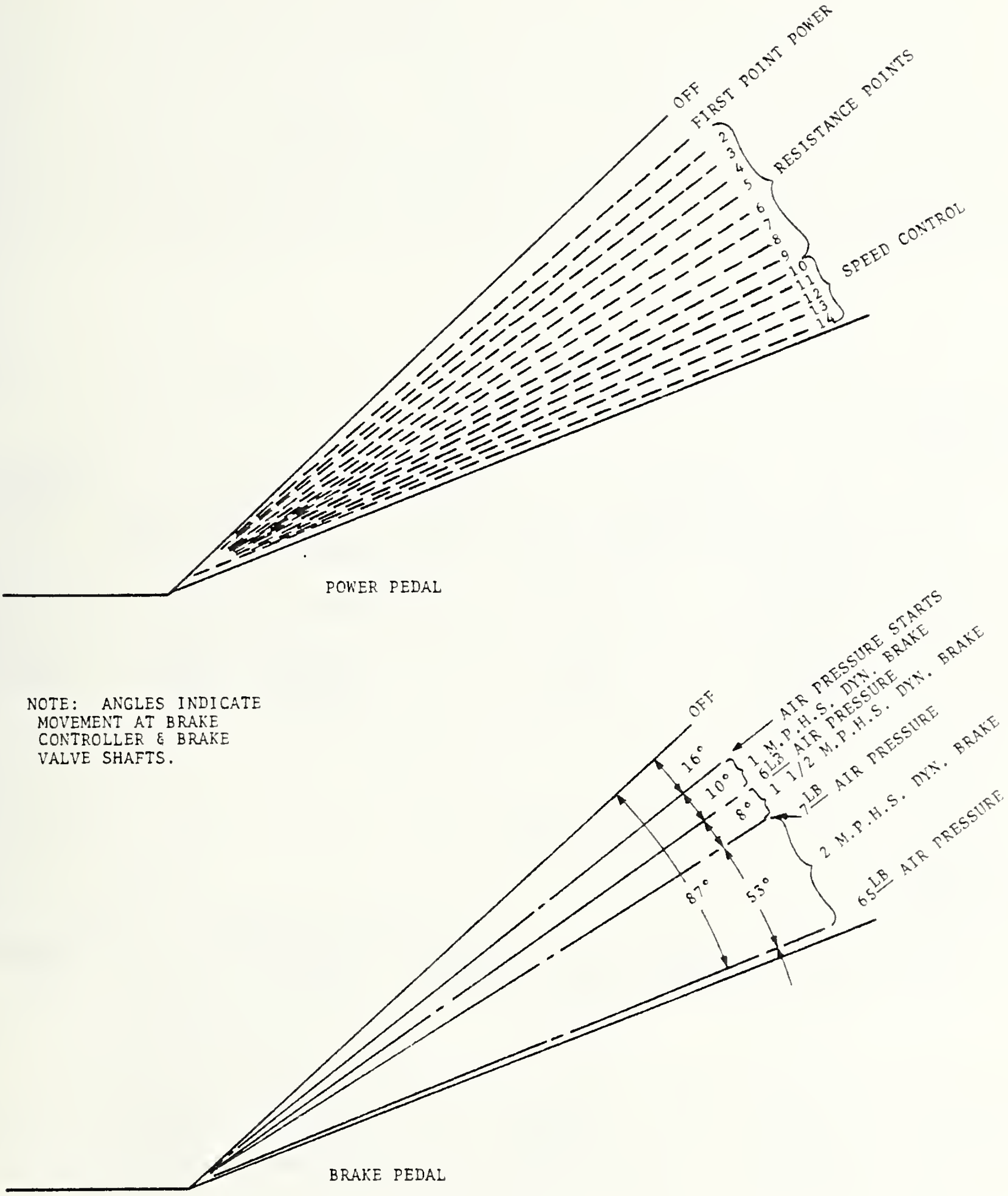
*Gradual increase from step 3 to 4 (full).

The MRC controller functions equally in both motoring and regenerative/dynamic braking modes. In the regenerative braking mode, the motor back EMF must exceed the terminal voltage. For a terminal voltage of 550 volts, this requires that the vehicle speed be greater than 18 mph. (See Figure 5.) To produce regenerative braking, the vehicle operator releases pressure on the power (accelerator) pedal, allowing the cam to assume a lower position within the 10-14 step range of the cam. Figure 5 shows the braking tractive effort realized for three values of shunt field current, while Figure 4 gives the corresponding armature current for different tractive efforts. Since the tractive force is negative in this case, armature current is likewise negative.

For dynamic (rheostatic) braking, the vehicle operator shifts control from the accelerator pedal to the brake pedal. Pushing down on the brake pedal causes the motor to be disconnected from the line and reconnected to a brake resistor. The DC machine then functions as a generator, converting the vehicle's kinetic energy into I^2R heat loss in the brake resistor. To supplement the braking effort, particularly at low vehicle speeds, friction braking is added. The way in which the power and brake pedals are related to vehicle tractive effort is illustrated in Figure 6.

2.3 MODES OF OPERATION

Block diagrams of power flow in motoring and braking modes of operation are shown in Figure 7. In the motoring modes, the power flows from the trolley wire through the power conditioning unit (PCU) to the traction motor. The output motor power then flows through the gearbox and drivetrain to the wheels. In the regenerative braking mode, the power flow is reversed in the main path. The controller maintains cruise speed by alternating between motoring and regenerative braking, with the net accelerating thrust averaging out to zero. Service braking is accomplished by a blend of dynamic and friction brakes. Three rates of deceleration are available from the dynamic braking system, corresponding to three values of shunt field resistance. Any deceleration rate is possible, however, by assuming an ideal blending of



NOTE: ANGLES INDICATE MOVEMENT AT BRAKE CONTROLLER & BRAKE VALVE SHAFTS.

FIGURE 6. SKETCH INDICATING POWER AND BRAKE PEDAL STEP POSITIONS

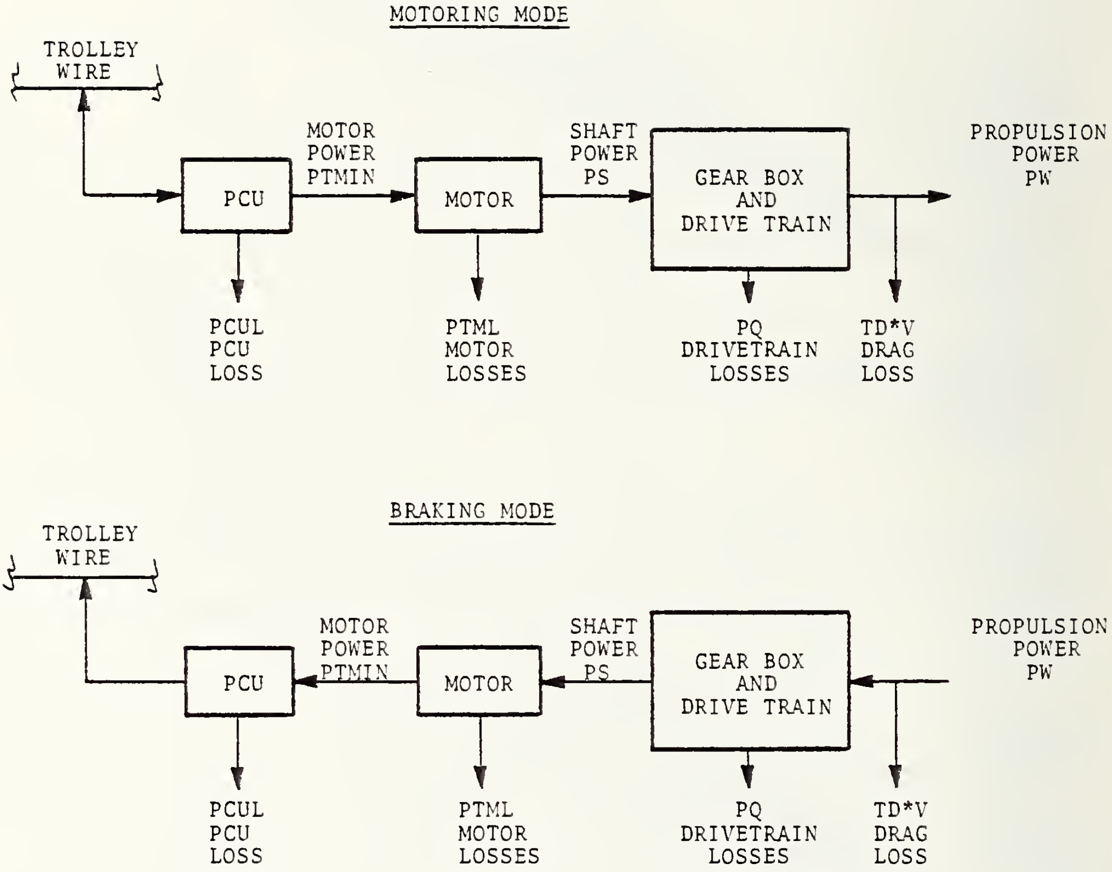


FIGURE 7. BLOCK DIAGRAM SHOWING POWER FLOW IN MOTORING AND BRAKING MODES

friction brakes. During dynamic braking, the PCU controls only the shunt field and auxiliary power, which is supplied from the line.

During acceleration, the armature current falls as the motor back EMF builds up. To maintain a constant acceleration, the vehicle operator "selects" a higher cam position, which causes an abrupt increase in armature current. From standstill to the final cruise velocity condition, the motor armature current undergoes successive abrupt transitions corresponding to the increasing cam positions. The manner in which the armature current varies in response to "requested" acceleration is shown in Figure 8 for the drive cycle C profile. The cam position step number is indicated in the figure for each interval in the drive cycle.

During cruise, the armature current is reduced in response to the lower tractive effort required to overcome the vehicle drag forces. Due to the coarseness of the controller action, the trolley bus model predicts alternately positive and negative tractive efforts as necessary to maintain a constant cruise velocity. This results in alternately positive and negative armature currents, as shown in Figure 8.

The deceleration mode uses regenerative, dynamic, and frictional braking to reduce the vehicle speed. In the regenerative and dynamic braking modes, motor armature current flows in the negative (reverse) direction as required to develop braking torque. For the case illustrated in Figure 8, in which dynamic and frictional braking are jointly utilized for decelerating the vehicle, the armature current shown is the current flowing through the braking resistor.

The choice of the particular braking mode used, whether regenerative, dynamic and/or frictional, is dictated by the amount of braking effort required for deceleration. Initially, regenerative braking is tried by the vehicle operator. If additional braking effort is required, the operator removes his foot from the motoring pedal and pushes down on the brake pedal. This results in a combination of dynamic and frictional braking sufficient to meet the required braking demands.

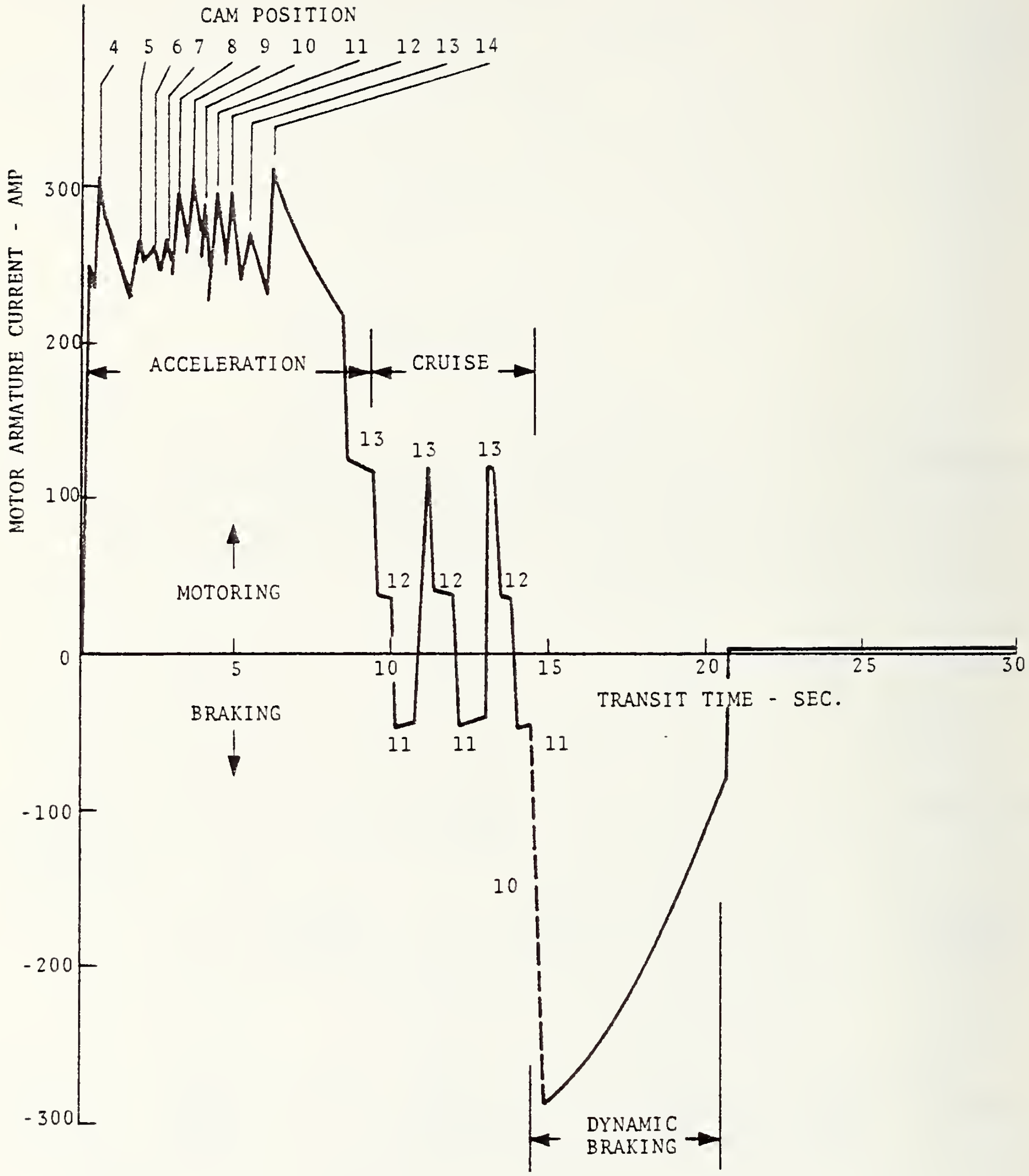


FIGURE 8. MOTOR ARMATURE CURRENT FOR DIFFERENT OPERATING MODES

3. TROLLEY BUS PERFORMANCE PROGRAM

The Trolley Bus Performance Program consists of a main program and three subroutines. The main program controls the execution and calls the subroutines in sequence. Each subroutine contains modeling equations which determine the operating characteristics of a part of the propulsion system.

The subroutine PROF determines the mission profile conditions at each program iteration. These conditions include acceleration, speed and position of the vehicle, roadway grade, and encountered headwind. PROF also computes the distance from the vehicle to the next stop and determines when to begin braking. Braking is done at a constant, but jerk-limited, deceleration rate that is specified by the driving cycle.

The subroutine MOTOR solves the motor modeling equations and determines the motor speed, armature and field current, generated emf and terminal voltage, power losses, and power input to the propulsion system from the trolley wires.

The subroutine PCU computes the power lost in the dc/dc power conditioning unit and the motor field controller, and also determines the power supplied to auxiliary systems.

The computer program calculates and prints out numerous system parameters at each time increment. Profile conditions, tractive force, motor parameters, and vehicle power and energy are printed in the data file FOR03.DAT. At the end of the run, a run summary is also printed in FOR03.DAT which contains the distance, time, and average speed of the mission, as well as the total energy consumed and the energy consumed per mile.

A plotting program has also been developed to graphically display variable system parameters in six-channel stripchart fashion on an off-line CALCOMP pen plotter. The plotting capability is further discussed in Section 3.3 of this report.

3.1 PROGRAM FLOW AND SUBROUTINE CALLING SEQUENCE

A simplified flowchart of the computer program is shown in Figure 9. Complete FORTRAN source listings are given in Section 4.0.

The subroutine PROF is called first to initialize parameters within that subroutine. On all subsequent calls to PROF, the initialization section is skipped. Page and column headings are then written in the output data file FOR03.DAT, and the program enters its main iteration loop.

At each time increment, the subroutine PROF is called to determine the mission profile conditions of acceleration, speed and position of the vehicle, roadway grade, and encountered headwind. PROF also computes the total drag force on the vehicle and determines when to begin braking so that the vehicle comes to rest at the correct position. The subroutine MOTOR is then called to compute the motor's performance characteristics and power input. The normal acceleration characteristic is obtained by maintaining the motor armature current at or above a specified setpoint. This is done by removing series resistors from the armature circuit in steps. There are 14 such steps corresponding to positions on a rheostatic cam controller. The subroutine PCU is then called to compute the PCU power losses and auxiliary load. The total power input to the vehicle and the total energy consumed since the start of the run are then computed.

The program then writes one line of data in the output file FOR03.DAT. If plots are desired, one line of data is also written in the file FOR22.DAT. (This file is required as input to the plotting program and contains the values of six time-varying system parameters that are to be displayed.) The time clock is then incremented if the end of the cycle has not been reached, and the program loops back to PROF for the next iteration.

A specified number of driving cycles are made per mile; and at the end of each cycle the stop index is incremented, page and column headings written, and the next cycle is begun. At the end

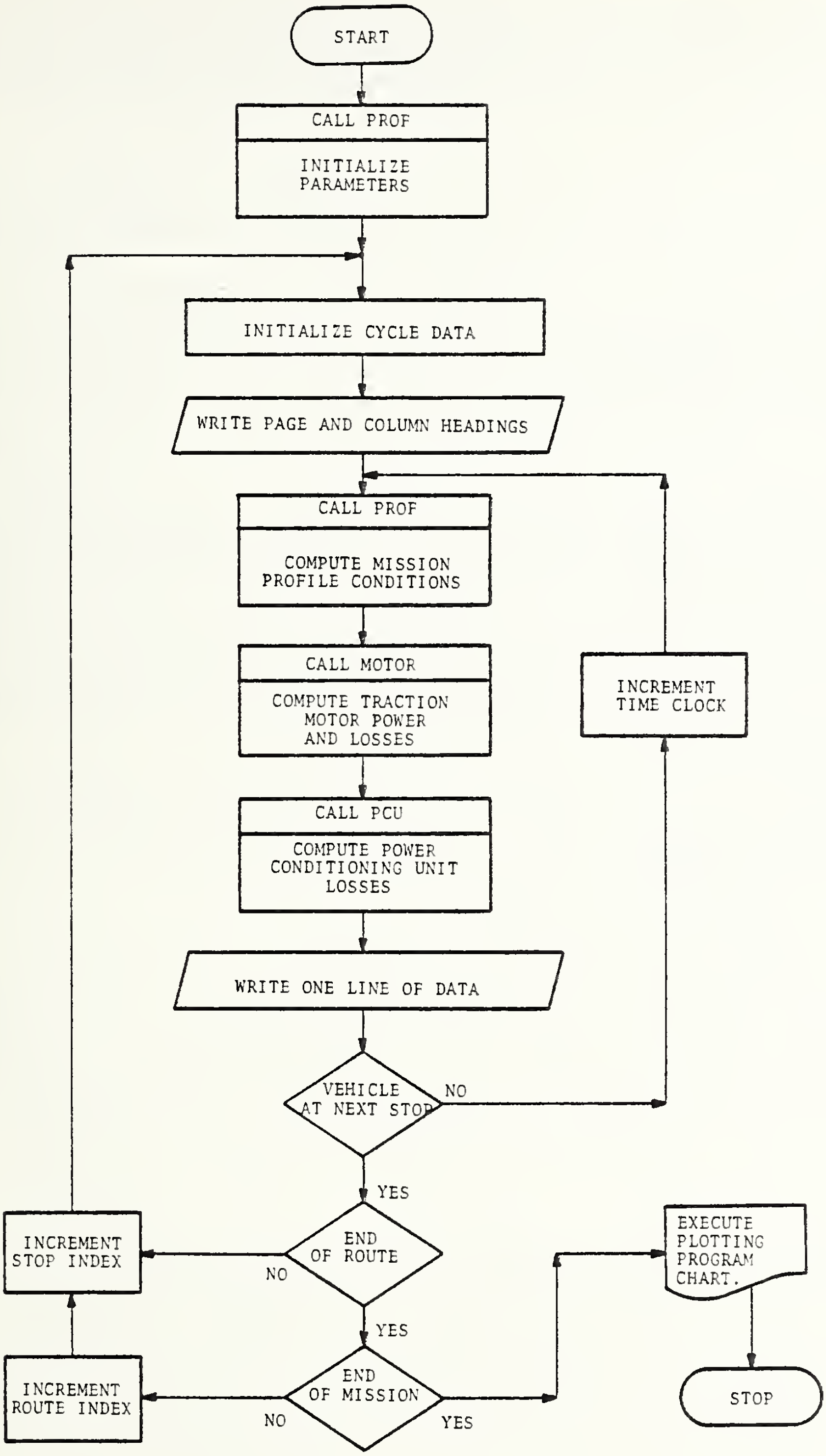


FIGURE 9. PROGRAM FLOWCHART

of a specified number of routes the mission is complete and the run summary calculations are performed and the results written in FOR03.DAT.

The plotting program CHART.FOR can then be executed to display any six time-varying system parameters on an off-line CALCOMP pen plotter.

3.2 EXECUTING THE PROGRAM

The main program and all subroutines are contained in separate source files. By not combining all subroutines into one file, compilation time is minimized in case changes must be made to only a few files. The main program and the three subroutines must be compiled and loaded into the computer's active core area before execution can begin. Loading is done using a command file, BUS3.CMD, which contains the names of all files that must be loaded. Section 5.6 contains a listing of BUS3.CMD, and the list of files to be loaded.

Once all files are compiled, the following command is typed on the user's terminal:

```
.EXECUTE @ BUS3.CMD
```

The subroutines are then loaded along with the main program, and execution begins. The program first asks the user to specify one of three typical driving cycles which determine cruising speed, deceleration rate, number of stops per mile, route length, etc. A "1" is typed, followed by a carriage return if Cycle A is desired, a "2" for Cycle B, or a "3" for Cycle C. The program then asks for a code number to indicate which type of data is desired. A "1" will cause the output data file FOR03.DAT to be generated. (See Section 4.5.) A "2" will generate the plot file FOR22.DAT, which can later be used by the plotting program to produce CALCOMP plots of system parameters. A "3" will generate both files, a "4" neither. The code number is typed, followed by a carriage return, and the program proceeds unassisted. At the end of execution, the file FOR03.DAT is automatically queued for printing on the line printer.

To print all files contained in the command file BUSL3.CMD (Section 4.6), the following command is given:

```
.LIST @ BUSL3.CMD
```

3.3 PLOTTING PROGRAM CHART.FOR

A plotting program has been developed to display any six time-varying system parameters on an off-line CALCOMP pen plotter. The program uses the standard CALCOMP subroutine calls, and writes instructions on a magnetic tape which are later interpreted by the plotting device to generate the plots. Figure 10 shows a sample plot for Driving Cycle C. The peak values of each parameter must be determined before execution, and appropriate y-axis scales must be chosen. These scale values are entered during execution of the program, as are labels for each of the six strip-charts and the x-axis length in inches. Section 5.7 contains a listing of the plotting program, which has the file name CHART.FOR.

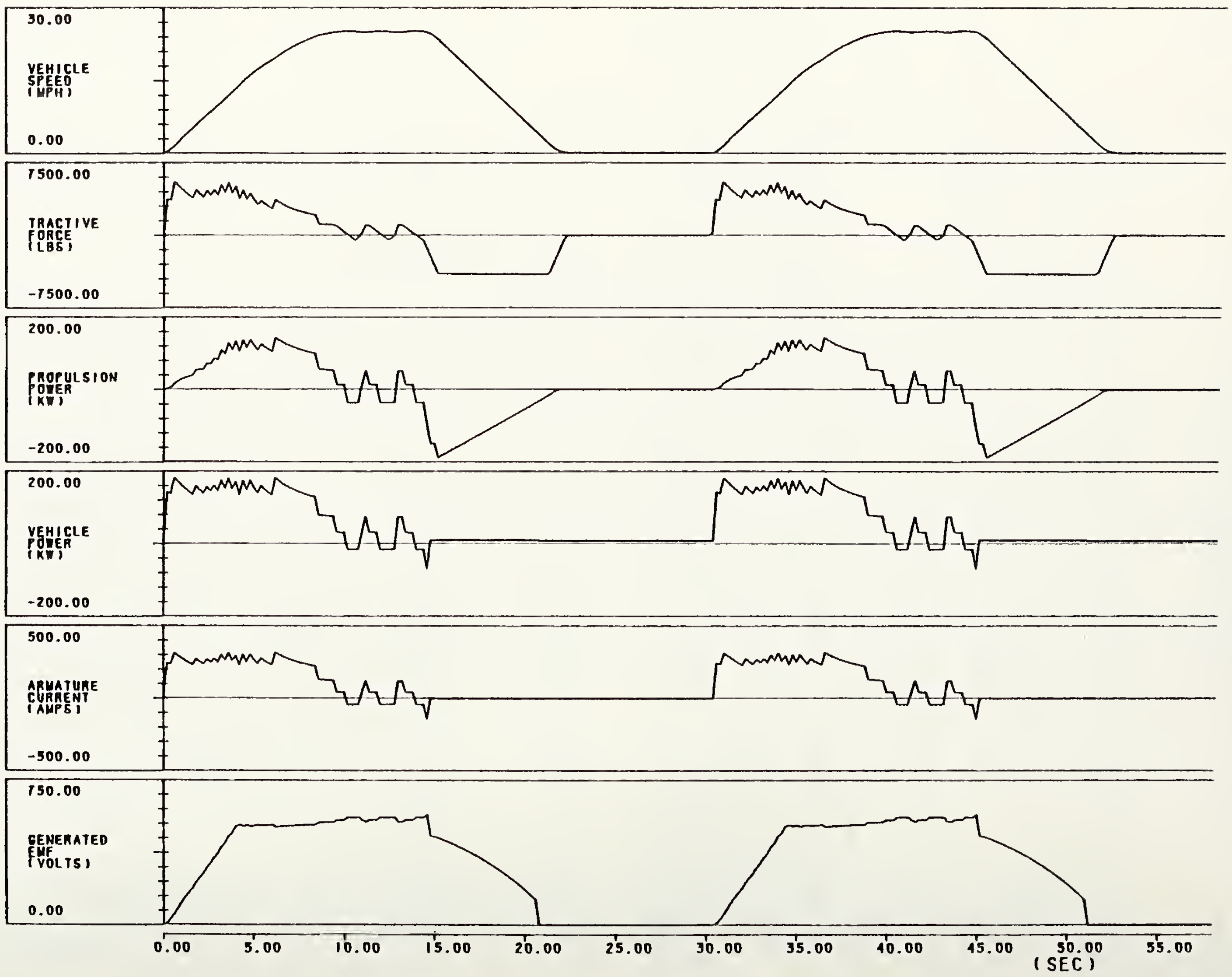


FIGURE 10. CALCOMP PLOT OF SYSTEM PARAMETERS - DRIVING CYCLE C

4. MODELING THEORY AND EQUATIONS

This section details the modeling theory used in simulating the propulsion system's components. The modeling equations are expressed in terms of FORTRAN symbols which appear later in the program listing. The values chosen for the system component parameters are nominal ones selected for the purpose of illustrating baseline system performance.

4.1 MISSION PROFILE EQUATIONS

The vehicle's mission profile is defined at the start of each run by selecting one of three typical driving cycles, called cycles A, B, and C. The driving cycles are completely specified by the various constants given in Table 1. The actual vehicle acceleration (ACC) is determined by the net accelerating thrust (TN) supplied by the propulsion system. During acceleration, a relay in the cam controller maintains the motor armature current (AMP) at or above the specified setpoint (SET). This is done by advancing the cam controller step (ICC) to the next position as the current falls below the setpoint. On the highest step (ICC=14) the vehicle is operating at its power limit, and the decreasing armature current is allowed to fall below the setpoint. The vehicle then accelerates at a reduced rate up to the cruise speed (VC). The jerk (AJERK) is constrained to be within a specified limit (AJERKR) during acceleration and deceleration. During cruise, the jerk limit is reduced in order to minimize force fluctuations as the cam controller maintains cruise speed by alternating between motoring and braking modes of operation.

The number of stops per mile (NS) specifies the distance between stops (SS), since equal stop spacing is assumed. The dwell time at each stop (DWELL) is the time allowed for passengers to enter or exit the vehicle. Additional dwell time at the end of the route (TAUMU) can be added to simulate a waiting period before the next transit of the route is begun. The number of passengers (NP) is used in computing the vehicle's gross weight (WT) and accelerating mass (AMASS). The route length (SR) times the number of transits of the route (NT) gives the total distance traveled by the vehicle.

The deceleration is always done at a constant but jerk-limited rate (DECL). For low braking forces at higher speeds, regeneration to the trolley wire occurs as the motor is switched to a generating configuration. For higher braking forces, however, the regenerated power is diverted from the trolley wire to dynamic resistors on board the vehicle. Any additional braking power to meet the required deceleration is absorbed by friction brakes. Below 4.0 mph, friction brakes are used exclusively. The braking is begun at a predetermined distance from the next stop so that the vehicle comes to rest at the proper location. Figure 3 shows the speed-time plot for one complete cycle of an arbitrary mission. The time segments for the deceleration are determined as follows:

1) T1 = DECL/AJERKR - Time from start of braking to start of constant deceleration [sec].

2) T2 = V/DECL - Time from start of braking to completion of constant deceleration [sec].

3) T3 = T1 + T2 = Total time of deceleration [sec].

4) T4 = T3 + DWELL = Time from start of braking to end of cycle [sec].

5) T4 = T5 + TAUMU = Additional time added between routes.

Where:

DECL = Constant deceleration rate (mph/sec).
AJERKR = Jerk limit (mph/sec^2).
V = Vehicle speed at start of braking (mph).
DWELL = Dwell time at each stop (sec).
TAUMU = Dwell time between routes (sec).

The stopping distance (XB) for the given deceleration rate (DECL) and vehicle speed (V) is computed as the product of the total time of deceleration (T3) times the average vehicle speed during deceleration (V/2.0). That is:

6) XB = (V/2.0) * T3/3600.0 = stopping distance (mi).

or:

7) XB = (V/2.0) * (DECL/AJERKR + V/DECL) / 3600.0

At each program iteration, the vehicle's acceleration is computed as the net accelerating thrust (TN) divided by the equivalent vehicle mass (AMASS). In computing AMASS, a factor of 2300.0 lbs is added to the vehicle's gross weight (WT) to account for rotary inertia of the propulsion system components.

8) ACC = TN/AMASS = Vehicle acceleration (mph/sec).

9) AMASS = (WT + 2300.0) / GEE = Vehicle accelerating mass (g-lbs).

10) WT = WTCRB + (NP+1) * WTP = Vehicle gross weight (lbf).

Where:

TN = Net accelerating thrust (lbf).
GEE = 21.927 = Acceleration due to gravity (mph/sec).
WTCRB = 22000.0 = Vehicle curb weight (lbf).
NP = Number of passengers.
WTP = 150.0 = Weight of a typical passenger (lbf).

The average vehicle acceleration (ABAR) over the computing time interval (TAU) is then determined and numerically integrated to determine the vehicle's speed (V) during that time interval. The average speed (VBAR) is similarly integrated to determine the distance traveled by the vehicle during each interval. The total time since the start of the run (THETA) is the sum of each computing time interval (TAU). During acceleration, cruise, and deceleration, TAU equals 0.05 seconds; but during dwell, when the system parameters vary slowly, TAU is increased to 0.2 seconds in order to reduce the total computing time. The total distance traveled by the vehicle since the start of the run (S) is the sum of the distances traveled during each iteration. The distance between the previous stop and the point at which braking (STAB) begins equals the distance between stops (SS) minus the stopping distance (XB). When the vehicle has gone the distance STAB, braking begins at the predefined deceleration rate (DECL), with allowances made for the specified jerk limit (AJERKR).

At each iteration, the drag forces acting on the vehicle are computed according to the following equations:

11) TG = WT * SIN(ATAN(GRADE)) = Grade drag (lbf).

12) TR = CR * WT = Rolling drag (lbf).

13) TA = 0.00258 * CD*AF*(V+HW)**2.0 = Aerodynamic drag (lbf).

14) TD = TG+TR+TA = Total drag force (lbf).

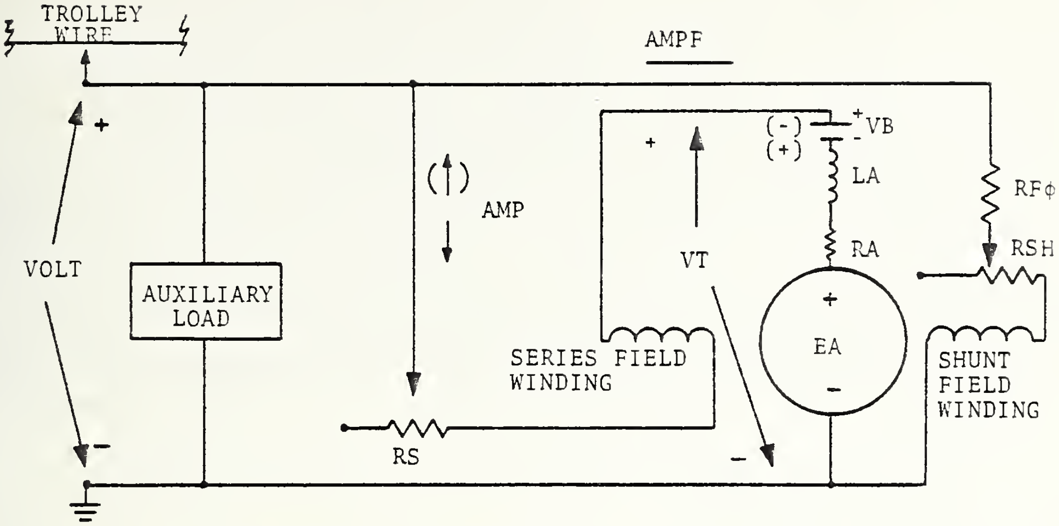
Where:

WT = Vehicle gross weight (lbf).
GRADE = Roadway grade (rad).
CR = 0.0075 = Rolling drag coefficient.
CD = 0.66 = Aerodynamic drag coefficient.
AF = 69.5 = Vehicle frontal area (ft^2).
V = Vehicle speed (mph).
HW = Encountered headwind (mph).

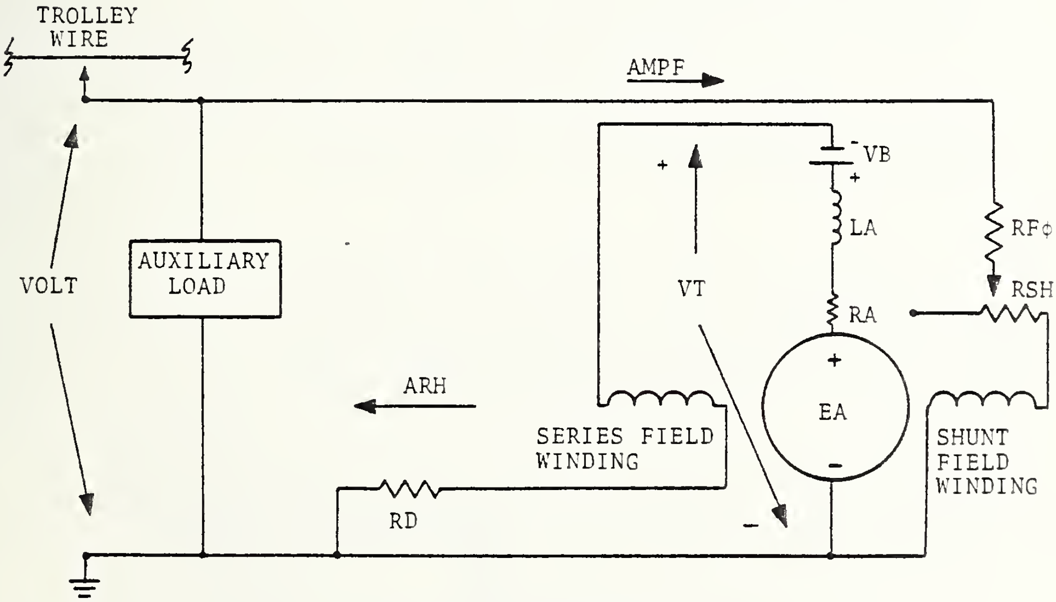
The grade data is stored in an array, G(25,2), which can contain up to 25 paired sets of grade values and the corresponding distances at which the grades are encountered. As the vehicle passes each distance at which the grade changes, a new value of GRADE is determined from the next indexed value in the array G(25,2). In this simulation, all grade values are zero.

4.2 MOTOR MODELING EQUATIONS

The dc traction motor has a shunt-wound field that is rheostatically controlled. The motor terminal voltage can be varied by adding or removing resistors in series with the armature circuit. A schematic diagram of the vehicle's propulsion system is shown in Figure 11. A 14-position cam controller regulates both series and shunt resistance values in the motoring and regenerative braking modes of operation. During acceleration, a relay maintains the armature current (AMP) at or above the specified setpoint (SET). This is done by advancing the cam controller to the next position



MOTORING AND REGENERATIVE BRAKING MODES



DYNAMIC BRAKING MODE

FIGURE 11. PROPULSION SYSTEM SCHEMATIC DIAGRAMS

as the current falls below the setpoint. Each higher cam position removes more series resistance from the armature circuit, thus increasing the motor terminal voltage. When the cam position indicator (ICC) equals 10, the series resistance is reduced to zero. The field weakening mode is entered at position 11, as the field resistance is increased on this and all higher cam positions. On the highest cam position (ICC=14) the power limit is encountered, and the vehicle accelerates at a reduced rate up to cruise speed (VC). Table 6 summarizes the values of series resistance (RS) and shunt resistance (RSH) for all 14 positions of the cam controller.

The motor speed (RPM) is related to the vehicle speed (V) by the following equation:

15) RPM = RATIO*TF*V=Motor speed (rpm).

Where:

RATIO = 11.59 = Reduction gear ratio
TF = 8.003 = Tire factor (rpm/mph).
V = Vehicle speed (mph).

The field current (AMPF) is computed as:

16) AMPF = VOLT/RF = Field current (amps).

Where:

VOLT = 550.0 = Trolley wire voltage (volts).
RF = RFO + RSH = Field resistance (ohms).
RFO = 83.0 = Constant resistance term (ohms).
RSH = Variable shunt resistance term (ohms).

The motor's magnetization curve is modeled by Equation 17, known as the Froelich Equation. Equation 17 is also plotted in Figure 12 for the 14 cam positions summarized in Table 6.

$$17)\quad EA = EAO * \frac{(AMP + SIGMA1*AMPF)}{(AMPO + AMP + SIGMA*AMPF)} * \frac{RPM}{1000.0}$$

TABLE 6. FROELICH EQUATION PARAMETERS

Motoring and Regenerative Braking				
ICC	RS	RSH	EAO	AMPO
1	3.197	99999.9	501.5	252.9
2	3.197	41.0	562.1	266.4
3	2.090	41.0	624.9	266.4
4	1.451	41.0	624.9	273.3
5	1.082	41.0	624.9	273.3
6	0.812	41.0	624.9	273.3
7	0.606	41.0	624.9	273.3
8	0.358	41.0	624.9	273.3
9	0.156	41.0	624.9	273.3
10	0.0	41.0	624.9	273.3
11	0.0	103.0	545.2	212.1
12	0.0	220.0	515.1	201.9
13	0.0	520.0	561.2	266.4
14	0.0	99999.9	501.5	252.9
Rheostatic Braking				
IREQ	RD	RSH	EAO	AMPO
1	1.451	103.0	616.4	336.0
2	1.451	41.0	616.4	336.0
3	1.451	9.0	616.4	336.0

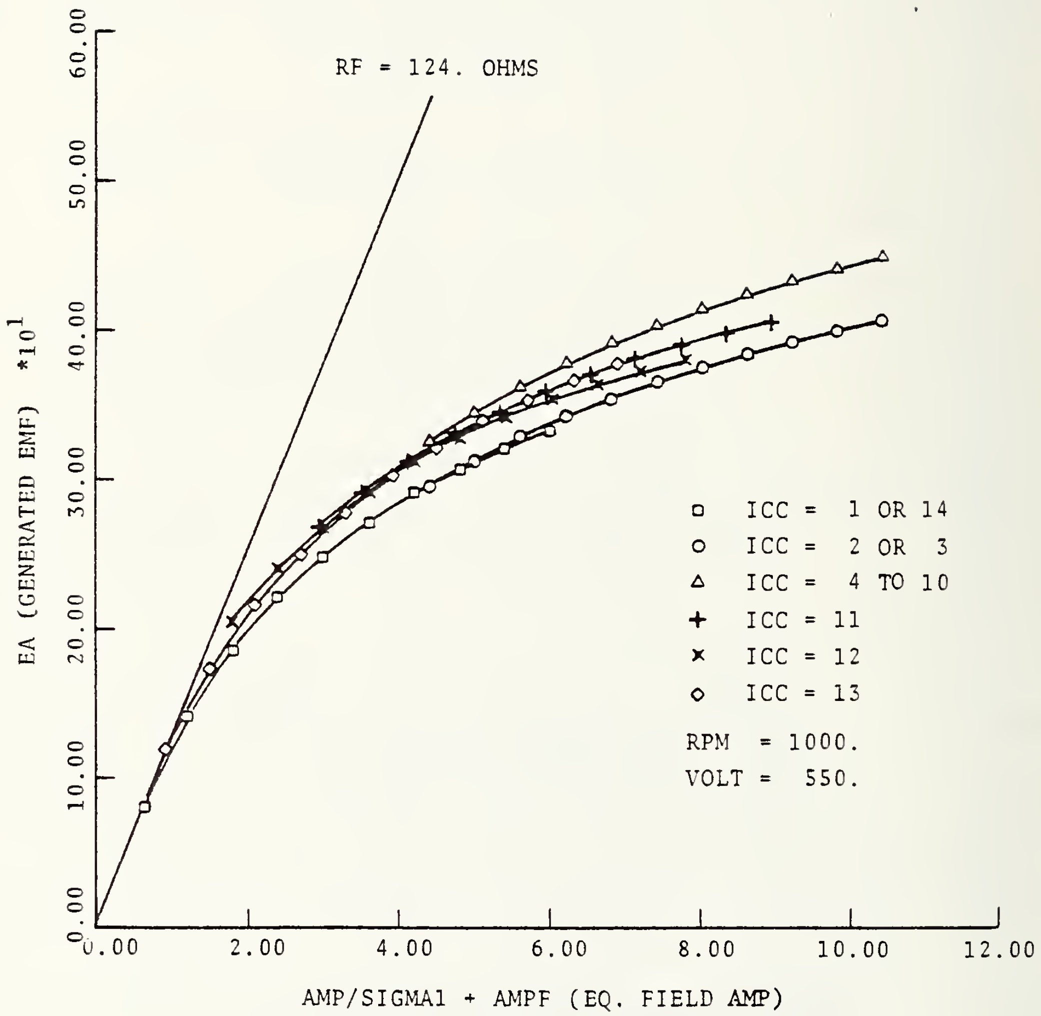


FIGURE 12. DC MOTOR MAGNETIZATION CURVES

Where:

EA = Generated emf (volts).
EAO = Base value of EA (volts).
AMP = Armature current (amps).
AMPF = Field current (amps).
AMPO = Constant current term (amps).
SIGMA = 82.916 = Field/armature turns ratio.
SIGMA = SIGMA1 + CAYPHI = Corrected turns ratio term.
CAYPHI = 15.0 = Flux correction term.
RPM = Motor speed (rpm).

Also, from Figure 11:

18) EA = VOLT - VB-AMP*R = Generated emf (volts).

Where:

VOLT = 550.0 = Trolley wire voltage (volts).
VB = 2.0 = Brush voltage drop (volts).
AMP = Armature current (amps).
R = RA+RS = Armature circuit resistance (ohms).
RA = Motor armature resistance (ohms).
RS = Added series resistance (ohms).

Equating Equations 17 and 18, thereby eliminating the variable EA, and solving the quadratic expression for the motor armature current (AMP) yields:

$$19)\quad AMP = \frac{-B+\sqrt{B**2.0 - 4.0 * C}}{2.0} = \text{Motor armature current (amp).}$$

Where:

B = AMPO + SIGMA*AMPF - (VOLT-VB)/R
+ EAO * RPM/(1000.0*R)

C = -(VOLT-VB) * (AMPO + SIGMA*AMPF)/R
+ EAO*RPM*SIGMA1*AMPF/(1000.0*R)

Once the armature current (AMP) is determined, the terminal voltage (VT), generated emf (EA), and air-gap power (P1) are computed by the following equations:

20) VT = VOLT - AMP*RS = Motor terminal voltage (volts).

21) EA = VT-VB-AMP*RA = Generated emf (volts).

22) P1 = EA*AMP/1000.0 = Air-gap power (kw).

NOTE: For regenerative braking, the sign of the brush voltage drop term (VB) must be reversed.

The motor loss terms are modeled by the following equations:

23) P2 = 3.39 E-04*RPM = Bearing loss term (kw).

24) P3 = 7.156 E-08*RPM**2.0 = Friction and windage loss term (kw).

25) P4 = 0.001 &RPM = Bearing loss term (kw).

26) P5 = 3.143 * (EA/550.0)**2.0 = Core loss term (kw).

27) P6 = 1.77 E-10*RPM**3.0 = Friction and windage loss term (kw).

28) P7 = P1-P2-P3-P4-P5-P6

29) P8 = 0.0099 * ABS (P7) = Stray load loss term (kw).

The motor shaft power (PS) is then:

30) PS = P7-P8 = Motor shaft power (kw).

The drive train losses (P9) are modeled by the following equation:

31) P9 = 1.5 E-06* (RPM/RATIO) **2.0
+ 0.06525 * ABS (PS) = Drive train losses (kw).

Where:

RPM = Motor speed (rpm).
RATIO = 11.59 - Reduction gear ratio.
PS = Motor shaft power (kw).

The available propulsion power (PW), tractive effort (TE), and net accelerating force (TN) are then computed as:

32) PW = PS-P9 = Propulsion power (kw).

33) TE = PW/(0.001989*V) = Tractive effort (lbf).

34) TN = TE-TD = Net accelerating force (lbf).

Where:

PS = Motor shaft power (kw).

P9 = Drive train power losses (kw).

V = Vehicle speed (mph).

TD = Total drag force on vehicle (lbf).

For rheostatic braking, the magnetization curve is modeled by the following equation:

35) $$EA = EAO*\frac{(ARH-SIGMA1*AMPF)}{(-AMPO+ARH-SIGMA*AMPF)} * \frac{RPM}{1000.0}$$

Where:

EA = Generated emf (volts).

EAO = Base value of EA (volts).

ARH = Rheostatic braking current (amps).

AMPF = Field current (amps).

AMPO = Constant current term (amps).

SIGMA1 = 82.916 = Field/armature turns ratio.

SIGMA = SIGMA1+CAYPHI = Corrected turns ratio term.

CAYPHI = 15.0 = Flux correction term.

RPM = Motor speed (rpm).

Also, from Figure 11:

36) $EA = ARH*(RA+RD)+VB$ = Generated emf in rheostatic braking mode (volts).

Eliminating EA from Equations 35 and 36 and solving the resulting quadratic for the rheostatic braking current (ARH) yields:

37) $$ARH = \frac{-BB- \sqrt{BB**2.0 - 4.0*CC}}{2.0}$$

Where:

$$BB = -(AMPO+SIGMA*AMPF-VB/(RA+RD) + EAO*RPM/(L000.0*(RA+RD)))$$

$$CC = - VB*(AMPO+SIGMA*AMPF)/(RA+RD) + EAO*RPM*SIGMA1*AMPF/(1000.0*(RA+RD))$$

Once the rheostatic braking current (ARH) is determined, the terminal voltage (VT), generated emf (EA), and airgap power (P1) are computed by the following equations:

38) VT = ARH*RD = Terminal voltage in rheostatic braking mode (volts)

39) EA = VT+ARH*RA+VB = Generated emf in rheostatic braking mode (volts).

40) P1 = -EA*ARH/1000.0 = Air-gap power in rheostatic braking mode (kw).

Where:

ARH = Rheostatic braking current (amps).
RD=1.451 = Rheostatic braking resistance (ohms).
RA=0.1267 = Armature resistance (ohms).
VB=2.0 = Brush voltage drop (volts).

During rheostatic braking, three decreasing values of field resistance (RSH) are tried in order to obtain the required braking thrust. These values are summarized in Table 6 along with the other parameters used in the Froelich Equation (Equation 35). If the required thrust exceeds that available with the rheostatic braking system, friction brakes supply the remainder of the braking thrust requirement. The motor and drive train loss terms apply to both motoring and braking modes of operation.

4.3 PCU MODELING EQUATIONS

The power conditioning unit (PCU) loss is the heating power dissipated in the series resistance (RS) that is added to the armature circuit for voltage control. Therefore:

41) PCUL = RS*AMP**2.0/1000.0 = Power conditioning unit loss (kw).

The motor field power (PTMF) is computed as follows:

42) PTMF = VOLT*AMPF/1000.0 = Traction motor field power (kw).

The total auxiliary power (PAUX) includes the field power (PTMF), and is determined by the following equation:

43) PAUX = PTMF+PECBLO+PAIR+
PLTG+PBC+PAC+PCBLO=
Total auxiliary power (kw).

Where:

RS = Armature series resistance (ohm).
AMP = Motor armature current (amp).
VOLT = 550.0 - Trolley wire voltage (volt).
AMPF = Field current (amp).
PECBLO = 0.6 = Environment control blower power (kw).
PAIR = 1.0 = Average air compressor load (kw).
PLTG = 3.6 = Lighting power (kw).
PBC = 2.0 = Average battery charger load (kw).
PAC = 6.0 = Air conditioning compressor power (kw).
PCBLO = 0.6 = Air conditioning condensor blower (kw).

The total input power to the motor (PTMA) is:

44) PTMA = VT*AMP/1000.0 = Motor input power (kw).

The total input power to the vehicle (PVEH) is then computed as:

45) PVEH = PTMA + PCUL + PAUL = Vehicle input power (kw).

Where:

VT = Motor terminal voltage (volt).
AMP = Motor armature current (amp).
PCUL = Power conditioning unit loss (kw).
PAUX = Total auxiliary power (kw).

5. FORTRAN SOURCE LISTINGS AND DATA FILES

5.1) MAIN3.FOR

```
C**** TROLLEY BUS PERFORMANCE PROGRAM:
      COMMON TAU1,IAC,IDC,VC,NS,SS,DWELL,TAUMU,NP,WT,SR,NT
      DATA  TAU1/1.0/,TIMX/0.2/,IAC/0/
C**** SPECIFY DRIVING CYCLE:
      WRITE(5,214)
      READ(5,215) IDC
C**** SPECIFY OUTPUT FILES:
      WRITE(5,218)
      READ(5,215) IOF
      IF((IOF.EQ.1).OR.(IOF.EQ.3)) I1=1
      IF((IOF.EQ.2).OR.(IOF.EQ.3)) I2=1
      WRITE(5,216)
C**** INITIALIZATION:
      I=1
      II=2
      JM=1
      CALL PROF(V,ACC,SET,GRADE,HW,S,SN,TN,TD,TS,T4,TAU,JM,ISW)
C**** INITIALIZE CYCLE DATA:
   35 ISW=1
      ACC=0.01
      V=0.01
      TAU=TAU1/20.0
      TIM=0.0
      IWC=1
      SN=SN+SS
      ICC=0
      IF(I1.NE.1) GO TO 40
C**** OUTPUT PAGE HEADING:
      WRITE(3,217)
C**** OUTPUT DRIVING CYCLE:
      IF(IDC.EQ.1) WRITE(3,211)
      IF(IDC.EQ.2) WRITE(3,212)
      IF(IDC.EQ.3) WRITE(3,213)
C**** OUTPUT AIR CONDITIONING STATUS:
      IF(IAC.EQ.1) WRITE(3,201)
      IF(IAC.EQ.0) WRITE(3,202)
C**** OUTPUT CYCLE DATA:
      WRITE(3,203) I,II,SS,NP,WT,VC,DWELL,HW
C**** OUTPUT COLUMN HEADINGS:
      WRITE(3,204)
C**** DETERMINE PROFILE CONDITIONS:
   40 CALL PROF(V,ACC,SET,GRADE,HW,S,SN,TN,TD,TS,T4,TAU,JM,ISW)
      IF(TS.GT.T4) GO TO 60     !END OF CYCLE!
C**** COMPUTE TRACTIVE FORCE AND PROPULSION POWER REQUIREMENT:
      TP=TN+TD
      PW=0.001989*TP*V
C**** COMPUTE MOTOR VOLTAGES, CURRENTS, AND AVAILABLE POWER:
  400 CALL MOTOR(AMP,SET,ARH,AMPF,VT,EA,V,VC,PS,PW,IE,TP,RS,IND,ICC)
```

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5.1) MAIN.3FOR (CONT)

```
C**** COMPUTE MOTOR TERMINAL POWER:
      PTMA=VT*AMP/1000.0
C**** UPDATE TRACTIVE AND ACCELERATING FORCES:
      IF(IND.EQ.1) TP=TE
      IF(IND.EQ.1) TN=TP-TD
C**** COMPUTE FRICTION BRAKING FORCE:
      IF(TP.LT.TE) TM=TP-TE
      IF(IND.LE.2) TM=0.0
C**** COMPUTE PCU LOSS AND AUXILIARY POWER:
      CALL PCU(AMP,AMPF,VT,RS,PCUL,PAUX,IAC)
C**** COMPUTE TOTAL INPUT POWER TO VEHICLE:
      PVEH=PTMA+PCUL+PAUX
      PBAR=(PVEH+PVEH1)/2.0
      PVEH1=PVEH
C**** COMPUTE TOTAL VEHICLE ENERGY:
      EVEH=EVEH+PBAR*TAU/3600.0
C**** OUTPUT TIME HISTORY OVER CYCLE:
      IF((IWC.EQ.1).AND.(I1.EQ.1)) WRITE(3,206) THETA,ACC,V,S,GRADE,
     *  ICC,IND,TP,TE,TM,TN,TD,PW,PS,AMP,ARH,VT,EA,PTMA,PVEH,EVEH
      IF((IWC.EQ.1).AND.(I2.EQ.1)) WRITE(22,219) THETA,V,TP,PW,PVEH,
     *  AMP,EA
      IWC=0
C**** INCREMENT PRINT CLOCK:
      TIM=TIM+TAU
      IF(TIM.GE.TIMX) IWC=1
      IF(TIM.GE.TIMX) TIM=0.0
C**** INCREMENT RUN TIME CLOCK:
      THETA=THETA+TAU
      IF(THETA.GT.100.0) STOP
      GO TO 40
C**** END OF CYCLE:
   60 TS=0.0
      I=I+1
      I1=I+1
      IF(S.GE.JM*SP-0.05) GO TO 65
      GO TO 35
C**** END OF ROUTE:
   65 JM=JM+1
      IF(S.GE.NT*SR-0.05) GO TO 70
      GO TO 35
C**** END OF MISSION:
   70 ESPC=EVEH/S
      VAVE=3600.0*S/THETA
      TMIN=THETA/60.0
C**** WRITE RUN SUMMARY:
      WRITE(3,207) S,TMIN,VAVE,EVEH,ESPC
  201 FORMAT(///,' AIR CONDITIONING ON',/)
  202 FORMAT(///,' AIR CONDITIONING OFF',/)
```

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5.1) MAIN3.FOR (CONT)

```
203 FORMAT(//,' FROM STOP',I4,' TO',I4,//,
   #   ' DISTANCE BETWEEN STOPS:          SS=',F7.3,' MI',//,
   #   ' NUMBER OF PASSENGERS:            NP=',I7,//,
   #   ' VEHICLE GROSS WEIGHT:            WT=',F7.0,' LBS',//,
   #   ' CRUISING SPEED:                  VC=',F7.1,' MPH',//,
   #   ' DWELL TIME:                   DWELL=',F7.1,' SEC',//,
   #   ' ENCOUNTERED HEADWIND:            HW=',F7.1,' MPH',//)
204 FORMAT(///,'  THETA   ACC     V    S  GRADE ICC IND      TP
   #      TE      TM      TN      TD     PW     PS    AMP    ARH     VT
   #   EA  PTMA  PVEH  EVEH',/)
206 FORMAT(1X,F6.1,F6.2,F6.1,F6.2,F6.3,2I4,5F7.0,8F6.1,F6.2)
207 FORMAT(1H1,//,' RUN SUMMARY:',//,
   #   ' TOTAL DISTANCE TRAVELLED:         S=',F7.2,' MI',//,
   #   ' TIME OF MISSION:               TMIN=',F7.2,' MIN',//,
   #   ' AVERAGE VEHICLE SPEED:         VAVE=',F7.2,' MPH',//,
   #   ' TOTAL ENERGY CONSUMED:         EVEH=',F7.2,' KW-HRS',//,
   #   ' SPECIFIC VEHICLE ENERGY:       ESPC=',F7.2,' KW-HRS/MI',//)
211 FORMAT(/,' DRIVING CYCLE A')
212 FORMAT(/,' DRIVING CYCLE B')
213 FORMAT(/,' DRIVING CYCLE C')
214 FORMAT(/,' ENTER DRIVING CYCLE:',/,
   #   ' TYPE "1" FOR A, "2" FOR B, "3" FOR C:',/)
215 FORMAT(I1)
216 FORMAT(/,' WORKING...',//)
217 FORMAT(1H1,///,' TROLLEY BUS PERFORMANCE PROGRAM',//)
218 FORMAT(/,' ENTER TYPE OF OUTPUT DESIRED:',/,
   #   ' TYPE "1" FOR DATA FILE FOR03.DAT,',/,
   #   ' TYPE "2" FOR PLOT FILE FOR22.DAT,',/,
   #   ' TYPE "3" FOR BOTH FILES,',/,
   #   ' TYPE "4" FOR NEITHER FILE:',/)
219 FORMAT(1X,7F10.3)
    STOP
    END
```

5.2) PROF3.FOR

```
      SUBROUTINE PROF(V,ACC,SET,GRADE,HW,S,SN,TN,TD,TS,T4,TAU,JM,ISW)
      DIMENSION G(25,2)
      COMMON TAU1,IAC,IDC,VC,NS,SS,DWELL,TAUMU,NP,WT,SR,NT
      DATA  GEE/21.927/,AJFRKR/3.5/,PHIR/0.0/,PHIW/0.0/,WS/0.0/,
     *  AF/69.5/,CD/0.66/,CR/0.0075/,WTCRB/22000.0/,WTP/150.0/
      IF(INI.EQ.1) GO TO 1000
      INI=1
C**** INITIALIZATION:
      IF(IDC.EQ.1) GO TO 1
      IF(IDC.EQ.2) GO TO 2
      IF(IDC.EQ.3) GO TO 3
C**** DRIVING CYCLE A:
    1 ACCM=3.5
      DECL=1.5
      VC=20.0
      NS=5
      SS=1.0/NS
      DWELL=12.0
      TAUMU=0.0
      NP=20
      SR=6.0
      NT=4
      SET=200.0
      GO TO 4
C**** DRIVING CYCLE B:
    2 ACCM=3.5
      DECL=3.5
      VC=25.0
      NS=8
      SS=1.0/NS
      DWELL=16.0
      TAUMU=0.0
      NP=10
      SR=6.0
      NT=4
      SET=250.0
      GO TO 4
C**** DRIVING CYCLE C:
    3 ACCM=3.0
      DECL=3.5
      VC=25.0
      NS=10
      SS=1.0/NS
      DWELL=8.0
      TAUMU=0.0
      NP=15
      SR=0.2
      NT=1
      SET=225.0
C**** COMPUTE VEHICLE GROSS WEIGHT AND ACCELERATING MASS:
```

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```
    4 WT=WTCRB+(NP+1)*WTP
      AMASS=(WT+2300.0)/GEE
C**** GRADE DATA:
      G(1,1)=0.0
      G(1,2)=0.0
      G(2,1)=100.0
      G(2,2)=0.0
      KG=1
      AJERK=AJERKR
      RETURN
C**** COMPUTE VEHICLE DYNAMICS:
 1000 ACC=TN/AMASS
      ABAR=(ACC+ACC1)/2.0
      ACC1=ACC
      V=V+ABAR*TAU
      VBAR=(V+V1)/2.0
      V1=V
      S=S+VBAR*TAU/3600.0
C**** DETERMINE HEADWIND AND GRADE:
      HW=-WS*COS(0.01745*(PHIK-PHIW))
   55 JG=KG+1
      IF(S.GE.G(JG,1)) GO TO 60
      GO TO 65
   60 KG=KG+1
      GO TO 55
   65 GRADE=G(KG,2)/100.0
C**** COMPUTE VEHICLE DRAG:
      TG=WT*SIN(ATAN(GRADE))
      TR=CF*WT
      TA=0.00256*CD*AF*(V+HW)**2.0*(V+HW)/ABS(V+HW+0.001)
      TD=TR+TA+TG
      IF(V.LE.0.01) TD=0.0
C**** STOPPING LOGIC & SPEED CONTROL:
      TNI=AJERKR*AMASS*TAU
      IF(ISW.EQ.0) GO TO 660
      XB=V*(DECL/AJERKR+V/DECL)/7200.0
      STAB=SN-XB
      IF(S.GE.STAB) GO TO 640
      IF(V.GT.VC) GO TO 110
      IF(V.GE.0.97*VC) GO TO 100
      IF(V.GE.(VC-ACC**2.0/AJERKR/2.0)) GO TO 95
      TN=TN+TNI
      IF(TN.GT.ACCM*AMASS) TN=ACCM*AMASS
      GO TO 120
C**** SPEED WITHIN DEADBAND:
   95 TN=TN-TNI
      IF(TN.LT.0.0) TN=0.0
      GO TO 120
  100 IF(TN.GT.0.0) TN=TN-TNI/3.0
      IF(TN.LT.0.0) TN=TN+TNI/3.0
```

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```
      GO TO 120
C**** OVERSPEED:
  110 TN=TN-TNI/3.0
      IF(TN.LT.-DECL*AMASS) TN=-DECL*AMASS
      GO TO 120
C**** INITIATE STOP:
  640 IF(ISW.EQ.1) GO TO 650
      GO TO 660
  650 ACC=0.0
      T1=DECL/AJERKR
      T2=V/DECL
      T3=T1+T2
      T4=T3+DWELL
      IF(S.GE.JM*SR-0.05) T4=T4+TAUMU
      ISW=0
      TS=0.0
  660 TS=TS+TAU
      IF(TS.GT.T1) GO TO 670
C**** ONSET:
      AJERK=-AJERKR
      GO TO 692
  670 IF(TS.GT.T2) GO TO 680
C**** DECELERATION:
      AJERK=0.0
      ACC=-DECL
      GO TO 694
  680 IF(TS.GT.T3) GO TO 690
C**** FLAIR:
      AJERK=AJERKR
      GO TO 692
  690 IF(TS.GT.T4) GO TO 120
C**** DWELL:
      AJERK=0.0
      ACC=0.0
      V=0.001
      TN=0.0
      TD=0.0
      S=SN
      TAU=TAU1/5.0
      GO TO 120
  692 ACC=ACC+AJERK*TAU
  694 TN=ACC*AMASS
  120 RETURN
      END
```

5.3) MOTOR3.FOR

```
      SUBROUTINE MOTOR(AMP,SET,ARH,AMPF,VT,EA,V,VC,PS,PW,TE,TP,RS,IND,
     *  ICC)
      DATA  RA/0.1267/,RD/1.451/,RATIO/11.59/,RF0/83.0/,TF/8.003/,
     *  VOLT/550.0/,SIGMA/97.916/,CAYPHI/15.0/,SIGMA1/82.916/,VB/2.0/,
     *  CAY2/3.39E-04/,CAY3/7.156E-08/,CAY4/0.001/,CAY5/3.143/,
     *  CAY6/1.77E-10/,CAY8/0.0099/,CAY9/1.5E-06/,CAY10/6.525E-02/,
     *  RS0/3.197/
      IF(V.GT.VC) GO TO 100
      IF(V.GT.0.01) GO TO 50
C**** VEHICLE AT REST:
      IND=0
      ICC=0
      GO TO 510
   50 IF(TP.GE.0.0) GO TO 300
C**** BRAKING:
      IF(V.GE.4.0) GO TO 100
C**** FULL FRICTION BRAKING:
      IND=4
      ICC=0
C**** TURN OFF MOTOR IF VEHICLE IS AT REST OR IN FRICTION BRAKING MODE:
  510 AMP=0.0
      ARH=0.0
      AMPF=0.0
      VT=0.0
      EA=0.0
      PS=0.0
      TE=0.0
      RETURN
  100 IF(ICC.LT.10) IND=3
      IF(IND.EQ.3) GO TO 200
      DO 550 INDX=2,3,1
      IND=INDX
      IF(IND.EQ.3) GO TO 200
C**** REGENERATIVE BRAKING:
      DO 550 ICCX=12,10,-1
      ICC=ICCX
      GO TO 10
C**** RHEOSTATIC BRAKING:
  200 DO 550 IREQX=1,3,1
      IREQ=IREQX
      ICC=0
      GO TO 3
C**** MOTORING:
  300 IND=1
      IF(ICC.EQ.0) ICC=1
      IF(V.GT.0.97*VC) ICC=10
  310 IF(ICC.GE.10) GO TO 10
      IF(ICC.GE.4) GO TO 4
      IF(ICC.EQ.1) RS=RS0
```

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```
      IF(ICC.EQ.1) RSH=99999.9
      IF(ICC.EQ.1) EAO=501.5
      IF(ICC.EQ.1) AMPO=252.9
      IF(ICC.EQ.2) RS=RSO
      IF(ICC.EQ.2) RSH=41.0
      IF(ICC.EQ.2) EAO=562.1
      IF(ICC.EQ.2) AMPO=266.4
      IF(ICC.EQ.3) RS=0.6537*RSO
      IF(ICC.EQ.3) RSH=41.0
      IF(ICC.EQ.3) EAO=562.1
      IF(ICC.EQ.3) AMPO=266.4
      GO TO 20
    4 IF(ICC.EQ.4) RS=0.4539*RSO
      IF(ICC.EQ.5) RS=0.3384*RSO
      IF(ICC.EQ.6) RS=0.2540*RSO
      IF(ICC.EQ.7) RS=0.1896*RSO
      IF(ICC.EQ.8) RS=0.1120*RSO
      IF(ICC.EQ.9) RS=0.0488*RSO
      RSH=41.0
      EAO=624.9
      AMPO=273.3
      GO TO 20
C**** MOTORING AND REGENERATIVE BRAKING:
   10 IF(ICC.EQ.10) RSH=41.0
      IF(ICC.EQ.10) EAO=624.9
      IF(ICC.EQ.10) AMPO=273.3
      IF(ICC.EQ.11) RSH=103.0
      IF(ICC.EQ.11) EAO=545.2
      IF(ICC.EQ.11) AMPO=212.1
      IF(ICC.EQ.12) RSH=220.0
      IF(ICC.EQ.12) EAO=515.1
      IF(ICC.EQ.12) AMPO=201.9
      IF(ICC.EQ.13) RSH=520.0
      IF(ICC.EQ.13) EAO=561.2
      IF(ICC.EQ.13) AMPO=266.4
      IF(ICC.EQ.14) RSH=99999.9
      IF(ICC.EQ.14) EAO=501.5
      IF(ICC.EQ.14) AMPO=252.9
      RS=0.0
      GO TO 20
C**** RHEOSTATIC BRAKING:
    3 IF(IREQ.EQ.1) RSH=103.0
      IF(IREQ.EQ.2) RSH=41.0
      IF(IREQ.EQ.3) RSH=9.0
      EAO=616.4
      AMPO=336.0
C**** COMPUTE MOTOR SPEED AND FIELD RESISTANCE AND CURRENT:
   20 RPM=RATIO*TF*V
      RF=RFO+RSH
      AMPF=VOLT/RF
      IF(IND.EQ.3) GO TO 30
```

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5.3) MOTOR3.FOR (CONT)

```
C**** MOTORING AND REGENERATIVE BRAKING:
      R=RA+RS
      B=AMP0+SIGMA*AMPF-(VOLT-VB)/R+EA0*RPM/(1000.0*R)
      C=-(VOLT-VB)*(AMP0+SIGMA*AMPF)/R+
     *  EA0*RPM*SIGMA1*AMPF/(1000.0*R)
C**** COMPUTE ARMATURE CURRENT:
      AMP=(-B+SQRT(B**2.0-4.0*C))/2.0
C**** COMPUTE MOTOR TERMINAL VOLTAGE:
      VT=VOLT-AMP*RS
C**** COMPUTE AIR-GAP EMF:
      EA=VT-AMP*RA-VB*AMP/ABS(AMP+0.001)
C**** COMPUTE AIR-GAP POWER:
      P1=EA*AMP/1000.0
      ARH=0.0
      GO TO 40
C**** RHEOSTATIC BRAKING:
   30 BB=-(AMP0+SIGMA*AMPF-VB/(RA+RD)+EA0*RPM/(1000.0*(RA+RD)))
      CC=-VB*(AMP0+SIGMA*AMPF)/(RA+RD)+
     *  EA0*RPM*SIGMA1*AMPF/(1000.0*(RA+RD))
C**** COMPUTE BRAKING CURRENT:
      ARH=(-BB-SQRT(BB**2.0-4.0*CC))/2.0
C**** COMPUTE MOTOR TERMINAL VOLTAGE:
      VT=ARH*RD
C**** COMPUTE AIR-GAP EMF:
      EA=VT+ARH*RA+VB
C**** COMPUTE AIR-GAP POWER:
      P1=-EA*ARH/1000.0
      AMP=0.0
C**** COMPUTE MOTOR POWER LOSSES:
   40 P2=CAY2*RPM
      P3=CAY3*RPM**2.0
      P4=CAY4*RPM
      P5=CAY5*(EA/550.0)**2.0
      P6=CAY6*RPM**3.0
      P7=P1-P2-P3-P4-P5-P6
      P8=CAY8*ABS(P7)
C**** COMPUTE MOTOR SHAFT POWER:
      PS=P7-P8
C**** COMPUTE DRIVE TRAIN LOSSES:
      P9=CAY9*(RPM/RATIO)**2.0+CAY10*ABS(PS)
C**** COMPUTE PROPULSION POWER AND TRACTIVE EFFORT:
      PW=PS-P9
      TE=PW/0.001989/V
      IF(IND.EQ.1) GO TO 560     !MOTORING!
      IF(IND.EQ.4) RETURN        !FULL FRICTION BRAKING!
      IF(TE.LE.TP) RETURN
  550 CONTINUE
      PW=0.001989*TP*V
      RETURN
  560 IF((V.GT.0.97*VC).AND.(TE.GE.TP)) RETURN
      IF(AMP.GE.SET) RETURN
      IF(ICC.LT.14) ICC=ICC+1
      IF(ICC.LT.14) GO TO 310
      RETURN
      END
```

5.4) PCU3.FOR

```
      SUBROUTINE PCU(AMP,AMPF,VT,RS,PCUL,PAUX,IAC)
      DATA  PAC/6.0/,PCBLO/0.6/,PECBLO/0.6/,PAIR/1.0/,PLTG/3.6/,
     *  PBC/2.0/,VOLT/550.0/
C**** COMPUTE POWER CONDITIONING UNIT LOSS:
      PCUL=RS*AMP**2.0/1000.0
C**** COMPUTE MOTOR FIELD POWER:
      PTMF=VOLT*AMPF/1000.0
C**** COMPUTE AUXILIARY POWER:
      PAUX=PTMF+PECBLO+PAIR+PLTG+PBC
      IF(IAC.EQ.1) PAUX=PAUX+PAC+PCBLO
      RETURN
      END
```

5.5) OUTPUT DATA FILE - FORO.3DAT - PARTIAL LISTING

```
TROLLEY BUS PERFORMANCE PROGRAM


DRIVING CYCLE C


AIR CONDITIONING OFF


FROM STOP    1 TO    2

DISTANCE BETWEEN STOPS:        SS=  0.100 MI

NUMBER OF PASSENGERS:          NP=      15

VEHICLE GROSS WEIGHT:          WT= 24100. LBS

CRUISING SPEED:                VC=    25.0 MPH

DWELL TIME:                DWELL=     6.0 SEC

ENCOUNTERED HEADWIND:          HW=     0.0 MPH



 THETA   ACC      V     S  GRADE ICC IND     TP      TE      TM     TN     ID    PW    PS   AMP   ARM    VT    EA  PTMA  PVEH  EVEH

   0.0  0.00    0.0  0.00 0.000   0   0    213.     0.     0.    213.    0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.00
   0.2  2.94    0.4  0.00 0.000   3   1   3725.  3725.     0.   3542.  183.   2.9   3.1 241.3   0.0  45.7  13.2  11.0 142.3  0.01
   0.4  2.91    1.0  0.00 0.000   3   1   3567.  3567.     0.   3364.  183.   6.9   7.3 232.6   0.0  63.9  32.4  14.9 137.6  0.01
   0.6  2.69    1.5  0.00 0.000   4   1   5504.  5504.     0.   5321.  183.  16.6  17.9 310.2   0.0  99.8  58.5  31.0 180.3  0.02
   0.8  4.12    2.3  0.00 0.000   4   1   5099.  5099.     0.   4916.  184.  23.6  25.3 290.9   0.0 127.9  89.1  37.2 169.6  0.03
   1.0  3.80    3.1  0.00 0.000   4   1   4718.  4718.     0.   4534.  184.  29.3  31.3 272.4   0.0 154.7 118.2  42.1 159.5  0.04
   1.2  3.51    3.9  0.00 0.000   4   1   4379.  4378.     0.   4193.  185.  33.5  35.9 255.7   0.0 178.9 144.5  45.7 150.3  0.05
   1.4  3.25    4.5  0.00 0.000   4   1   4073.  4073.     0.   3887.  185.  36.7  39.2 240.5   0.0 200.8 168.4  48.3 142.0  0.06
   1.6  3.02    5.2  0.00 0.000   4   1   3798.  3798.     0.   3612.  186.  38.9  41.7 226.8   0.0 220.8 190.1  50.1 134.4  0.07
   1.8  3.70    5.9  0.00 0.000   5   1   4649.  4649.     0.   4462.  187.  54.2  58.0 270.0   0.0 257.9 221.5  69.6 158.2  0.07
   2.0  3.41    6.6  0.00 0.000   5   1   4242.  4242.     0.   4053.  188.  55.5  59.4 250.0   0.0 279.6 245.9  69.9 147.1  0.08
   2.2  3.11    7.2  0.00 0.000   5   1   3885.  3885.     0.   3696.  189.  55.9  59.8 232.1   0.0 298.8 267.4  69.4 137.3  0.09
   2.4  3.76    7.9  0.00 0.000   6   1   4564.  4564.     0.   4373.  190.  71.6  76.6 266.6   0.0 333.5 297.7  68.9 156.3  0.10
   2.6  3.29    8.6  0.00 0.000   6   1   4090.  4090.     0.   3898.  192.  69.8  74.7 243.1   0.0 352.6 319.8  85.7 143.4  0.11
   2.8  2.95    9.2  0.00 0.000   7   1   4662.  4662.     0.   4469.  193.  85.4  91.4 272.1   0.0 385.1 348.6 104.8 159.3  0.12
   3.0  3.32    9.9  0.00 0.000   7   1   4103.  4103.     0.   3909.  195.  80.8  86.4 244.3   0.0 401.9 368.9  98.2 144.0  0.12
   3.2  2.91   10.5  0.00 0.000   8   1   5172.  5172.     0.   4976.  196. 108.2 115.8 297.7   0.0 443.4 403.7 132.0 173.4  0.13
   3.4  3.57   11.3  0.01 0.000   8   1   4351.  4351.     0.   4153.  198.  97.5 104.4 257.4   0.0 457.8 423.2 117.9 151.2  0.14
   3.6  2.99   11.9  0.01 0.000   9   1   5412.  5412.     0.   5212.  200. 128.4 137.3 310.0   0.0 501.6 460.1 155.5 180.2  0.15
   3.8  3.56   12.7  0.01 0.000   9   1   4286.  4286.     0.   4084.  202. 108.2 115.8 254.8   0.0 510.2 476.0 130.0 149.8  0.16
   4.0  4.26   13.4  0.01 0.000  10   1   5013.  5013.     0.   4809.  204. 133.3 142.6 291.2   0.0 550.0 511.1 160.2 169.8  0.17
   4.2  3.09   14.1  0.01 0.000  10   1   3700.  3700.     0.   3493.  207. 103.7 111.0 225.5   0.0 550.0 519.4 124.0 133.7  0.18
   4.4  3.98   14.8  0.01 0.000  11   1   4619.  4619.     0.   4410.  209. 136.3 145.9 298.9   0.0 550.0 510.1 164.4 173.2  0.19
   4.6  3.21   15.5  0.01 0.000  11   1   3689.  3689.     0.   3469.  212. 113.6 121.6 238.2   0.0 550.0 516.6 136.5 145.3  0.19
   4.8  3.48   16.1  0.01 0.000  12   1   4274.  4274.     0.   4060.  214. 136.8 146.4 300.6   0.0 550.0 509.9 165.3 173.5  0.20
   5.0  2.91   16.7  0.01 0.000  12   1   3614.  3614.     0.   3398.  216. 120.3 128.7 263.6   0.0 550.0 514.5 145.0 153.2  0.21
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5.5) OUTPUT DATA FILE - FORO.3DAT - PARTIAL LISTING (CONT)

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THETA    ACC      V      S  GRADE  ICC  IND       TP       TE       TH       TN    TD    PW    PS   AMP    ARH    VT    EA  PTMA  PVEH   EVEH

  5.2   2.49   17.3   0.01  0.000   12    1    3139.    3139.       0.    2921.  218. 107.8 115.4 236.2    0.0 550.0 518.1 129.9 138.1   0.22
  5.4   2.79   17.8   0.01  0.000   13    1    3516.    3516.       0.    3296.  220. 124.3 133.0 273.3    0.0 550.0 513.4 150.3 158.0   0.23
  5.6   2.49   18.3   0.01  0.000   13    1    3184.    3184.       0.    2961.  223. 115.9 124.1 254.8    0.0 550.0 515.7 140.1 147.8   0.24
  5.8   2.26   18.8   0.02  0.000   13    1    2917.    2917.       0.    2692.  225. 108.9 116.6 239.6    0.0 550.0 517.6 131.8 139.5   0.24
  6.0   2.07   19.2   0.02  0.000   13    1    2696.    2696.       0.    2469.  227. 103.0 110.3 226.8    0.0 550.0 519.3 124.8 132.5   0.25
  6.2   2.86   19.7   0.02  0.000   14    1    3630.    3630.       0.    3401.  229. 142.1 152.1 315.0    0.0 550.0 508.1 173.2 180.4   0.26
  6.4   2.62   20.2   0.02  0.000   14    1    3355.    3355.       0.    3124.  231. 135.0 144.5 299.0    0.0 550.0 510.1 164.5 171.7   0.27
  6.6   2.42   20.7   0.02  0.000   14    1    3127.    3127.       0.    2893.  234. 128.9 138.0 285.6    0.0 550.0 511.8 157.1 164.3   0.28
  6.8   2.25   21.2   0.02  0.000   14    1    2934.    2934.       0.    2698.  236. 123.7 132.4 274.1    0.0 550.0 513.3 150.8 158.0   0.29
  7.0   2.11   21.6   0.02  0.000   14    1    2768.    2768.       0.    2530.  238. 119.1 127.5 264.2    0.0 550.0 514.5 145.3 152.5   0.30
  7.2   1.99   22.0   0.02  0.000   14    1    2624.    2624.       0.    2384.  241. 115.1 123.2 255.4    0.0 550.0 515.6 140.5 147.7   0.31
  7.4   1.88   22.4   0.02  0.000   14    1    2498.    2498.       0.    2255.  243. 111.4 119.3 247.6    0.0 550.0 516.6 136.2 143.4   0.31
  7.6   1.78   22.8   0.03  0.000   14    1    2386.    2386.       0.    2141.  245. 108.2 115.8 240.7    0.0 550.0 517.5 132.4 139.6   0.32
  7.8   1.69   23.1   0.03  0.000   14    1    2286.    2286.       0.    2039.  246. 105.2 112.6 234.4    0.0 550.0 518.3 128.9 136.1   0.33
  8.0   1.62   23.5   0.03  0.000   14    1    2195.    2195.       0.    1947.  248. 102.5 109.7 228.7    0.0 550.0 519.0 125.8 133.0   0.34
  8.2   1.55   23.8   0.03  0.000   14    1    2114.    2114.       0.    1864.  250. 100.0 107.1 223.5    0.0 550.0 519.7 122.9 130.1   0.34
  8.4   1.48   24.1   0.03  0.000   14    1    2039.    2039.       0.    1788.  252.  97.7 104.6 218.7    0.0 550.0 520.3 120.3 127.5   0.35
  8.6   0.72   24.4   0.03  0.000   13    1    1126.    1126.       0.     872.  253.  54.6  58.4 125.7    0.0 550.0 532.0  69.7  77.4   0.36
  8.8   0.70   24.5   0.03  0.000   13    1    1100.    1100.       0.     845.  254.  53.6  57.4 124.8    0.0 550.0 532.2  68.6  76.3   0.36
  9.0   0.68   24.6   0.04  0.000   13    1    1075.    1075.       0.     820.  255.  52.7  56.4 123.0    0.0 550.0 532.4  67.7  75.4   0.37
  9.2   0.66   24.8   0.04  0.000   13    1    1052.    1052.       0.     796.  256.  51.8  55.5 121.3    0.0 550.0 532.6  66.7  74.4   0.37
  9.4   0.64   24.9   0.04  0.000   13    1    1030.    1030.       0.     773.  256.  51.0  54.6 119.7    0.0 550.0 532.8  65.9  73.6   0.37
  9.6   0.57   25.0   0.04  0.000   12    2     877.     239.       0.     620.  257.  11.9  12.8  39.9    0.0 550.0 542.9  22.0  30.2   0.38
  9.8   0.33   25.1   0.04  0.000   12    2     594.     225.       0.     336.  258.  11.3  12.1  38.8    0.0 550.0 543.1  21.3  29.5   0.38
 10.0   0.10   25.2   0.04  0.000   12    2     310.     219.       0.      52.  258.  11.0  11.8  38.2    0.0 550.0 543.2  21.0  29.2   0.38
 10.2  -0.13   25.2   0.04  0.000   11    2      26.    -764.       0.    -232.  258. -38.2 -35.8 -47.5    0.0 550.0 558.0 -26.1 -17.3   0.38
 10.4  -0.37   25.1   0.04  0.000   11    2    -259.    -757.       0.    -516.  258. -37.8 -35.5 -46.8    0.0 550.0 557.9 -25.8 -16.9   0.38
 10.6  -0.50   25.0   0.05  0.000   11    2    -544.    -744.       0.    -801.  257. -37.0 -34.7 -45.6    0.0 550.0 557.8 -25.1 -16.2   0.38
 10.8  -0.18   24.9   0.05  0.000   11    2    -260.    -727.       0.    -516.  256. -36.0 -33.8 -44.0    0.0 550.0 557.6 -24.2 -15.4   0.38
 11.0  -0.25   24.8   0.05  0.000   12    1     269.     269.       0.      13.  256.  13.3  14.3  42.6    0.0 550.0 542.6  23.4  31.6   0.38
 11.2   0.65   24.9   0.05  0.000   13    1    1036.    1036.       0.     780.  256.  51.3  54.9 120.7    0.0 550.0 532.8  66.1  73.8   0.38
 11.4   0.63   25.0   0.05  0.000   12    2     949.     244.       0.     692.  257.  12.1  13.0  40.4    0.0 550.0 542.9  22.2  30.4   0.39
 11.6   0.39   25.1   0.05  0.000   12    2     665.     229.       0.     408.  258.  11.4  12.3  39.1    0.0 550.0 543.0  21.5  29.7   0.39
 11.8   0.16   25.2   0.05  0.000   12    2     382.     221.       0.     124.  258.  11.1  11.9  38.4    0.0 550.0 543.1  21.1  29.3   0.39
 12.0  -0.07   25.2   0.06  0.000   11    2      98.    -764.       0.    -160.  258. -38.3 -35.9 -47.5    0.0 550.0 558.0 -26.1 -17.3   0.39
 12.2  -0.31   25.1   0.06  0.000   11    2    -187.    -759.       0.    -444.  258. -37.9 -35.6 -47.0    0.0 550.0 558.0 -25.8 -17.0   0.39
 12.4  -0.54   25.0   0.06  0.000   11    2    -471.    -747.       0.    -729.  257. -37.2 -34.9 -45.9    0.0 550.0 557.8 -25.2 -16.4   0.39
 12.6  -0.54   24.9   0.06  0.000   11    2    -330.    -735.       0.    -587.  257. -36.2 -33.9 -44.3    0.0 550.0 557.6 -24.4 -15.5   0.39
 12.8  -0.31   24.8   0.06  0.000   11    2     -46.    -718.       0.    -302.  256. -35.5 -33.3 -43.2    0.0 550.0 557.5 -23.8 -14.9   0.39
 13.0   0.65   24.8   0.06  0.000   13    1    1042.    1042.       0.     786.  256.  51.5  55.1 120.7    0.0 550.0 532.7  66.4  74.1   0.39
 13.2   0.63   25.0   0.06  0.000   13    1    1021.    1021.       0.     764.  257.  50.7  54.3 119.1    0.0 550.0 532.9  65.5  73.2   0.39
 13.4   0.51   25.1   0.07  0.000   12    2     803.     232.       0.     545.  257.  11.6  12.4  39.3    0.0 550.0 543.0  21.6  29.8   0.39
 13.6   0.27   25.2   0.07  0.000   12    2     519.     220.       0.     261.  258.  11.0  11.9  38.3    0.0 550.0 543.1  21.1  29.3   0.40
 13.8   0.04   25.2   0.07  0.000   12    2     235.     216.       0.     -23.  258.  10.8  11.6  37.9    0.0 550.0 543.2  20.9  29.1   0.40
 14.0  -0.19   25.2   0.07  0.000   11    2     -49.    -766.       0.    -307.  259. -38.3 -35.9 -47.6    0.0 550.0 558.0 -26.2 -17.4   0.40
 14.2  -0.43   25.1   0.07  0.000   11    2    -334.    -757.       0.    -591.  258. -37.8 -35.5 -46.8    0.0 550.0 557.9 -25.8 -16.9   0.40
 14.4  -0.70   25.0   0.07  0.000   11    2    -595.    -747.       0.    -852.  257. -37.2 -34.9 -45.9    0.0 550.0 557.8 -25.2 -16.4   0.40
 14.6  -1.40   24.7   0.07  0.000   11    2   -1449.   -2033.       0.   -1705.  256.-100.4 -94.2-147.6    0.0 550.0 570.7 -81.2 -71.5   0.39
 14.8  -2.10   24.6   0.08  0.000    0    3   -2303.   -3092.       0.   -2557.  254.-151.0-141.7     0.0  289.3 419.7 458.4   0.0  10.5   0.39
 15.0  -2.80   24.1   0.08  0.000    0    3   -3158.   -3098.     -70.   -3409.  252.-151.3-138.9     0.0  286.5 415.7 454.0   0.0  10.5   0.39
 15.2  -1.50   23.5   0.08  0.000    0    3   -4014.   -3082.    -932.   -4262.  248.-187.6-135.2     0.0  282.7 410.2 448.1   0.0  10.5   0.39
 15.4  -1.50   22.8   0.08  0.000    0    3   -4017.   -3073.    -945.   -4262.  245.-182.2-130.8     0.0  278.2 403.7 440.9   0.0  10.5   0.39
 15.6  -1.50   22.1   0.08  0.000    0    3   -4021.   -3061.    -960.   -4262.  241.-176.8-126.3     0.0  273.5 396.8 433.5   0.0  10.5   0.39
 15.8  -1.50   21.4   0.08  0.000    0    3   -4025.   -3048.    -977.   -4262.  237.-171.4-121.8     0.0  268.6 389.7 425.8   0.0  10.5   0.39
 16.0  -1.50   20.7   0.08  0.000    0    3   -4028.   -3031.    -997.   -4262.  234.-165.9-117.2     0.0  263.5 382.4 417.8   0.0  10.5   0.39
 16.2  -1.50   20.0   0.08  0.000    0    3   -4032.   -3012.   -1019.   -4262.  230.-160.4-112.5     0.0  258.3 374.8 409.5   0.0  10.5   0.39
 16.4  -1.50   19.3   0.09  0.000    0    3   -4035.   -2990.   -1045.   -4262.  227.-154.9-107.8     0.0  252.9 366.9 400.9   0.0  10.5   0.39
 16.6  -1.50   18.6   0.09  0.000    0    3   -4038.   -2965.   -1073.   -4262.  224.-149.4-103.0     0.0  247.2 358.7 392.1   0.0  10.5   0.39
 16.8  -1.50   17.9   0.09  0.000    0    3   -4041.   -2936.   -1105.   -4262.  221.-143.9 -98.1     0.0  241.4 350.3 382.9   0.0  10.5   0.40
 17.0  -1.50   17.2   0.09  0.000    0    3   -4044.   -2904.   -1140.   -4262.  218.-138.4 -93.3     0.0  235.4 341.5 373.3   0.0  10.5   0.40
 17.2  -1.50   16.5   0.09  0.000    0    3   -4047.   -2868.   -1179.   -4262.  215.-132.9 -88.4     0.0  229.1 332.4 363.4   0.0  10.5   0.40
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5.5) OUTPUT DATA FILE - FORO.3DAT - PARTIAL LISTING (CONT)

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THETA   ACC     V     S GRADE ICC IND     TF     TE     TM     TN     TD    PW    PS   AMP   ARH    VT    EA  PTHA  PVEH  EVEH

 17.4 -3.50  15.8  0.09 0.000   0   3 -4049. -2827. -1222. -4262.   213.-127.3 -83.4   0.0 222.6 323.0 353.7   0.0  10.5  0.40
 17.6 -3.50  15.1  0.09 0.000   0   3 -4052. -2782. -1270. -4262.   210.-121.7 -78.4   0.0 215.9 313.7 342.6   0.0  10.5  0.40
 17.8 -3.50  14.4  0.09 0.000   0   3 -4054. -2737. -1323. -4262.   208.-116.2 -73.5   0.0 208.0 303.1 331.6   0.0  10.5  0.40
 18.0 -3.50  13.7  0.09 0.000   0   3 -4057. -2676. -1380. -4262.   205.-110.6 -68.5   0.0 201.7 292.6 320.7   0.0  10.5  0.40
 18.2 -3.50  13.0  0.09 0.000   0   3 -4059. -2616. -1443. -4262.   203.-105.0 -63.5   0.0 194.2 281.7 308.3   0.0  10.5  0.40
 18.4 -3.50  12.3  0.09 0.000   0   3 -4061. -2549. -1512. -4262.   201. -99.4 -58.6   0.0 186.4 270.5 296.1   0.0  10.5  0.40
 18.6 -3.50  11.6  0.09 0.000   0   3 -4063. -2476. -1586. -4262.   199. -93.8 -53.7   0.0 178.4 258.9 283.4   0.0  10.5  0.40
 18.8 -3.50  10.9  0.10 0.000   0   3 -4065. -2397. -1668. -4262.   197. -88.2 -48.8   0.0 170.0 246.7 270.3   0.0  10.5  0.40
 19.0 -3.50  10.2  0.10 0.000   0   3 -4067. -2311. -1756. -4262.   195. -82.6 -44.0   0.0 161.4 234.2 256.7   0.0  10.5  0.40
 19.2 -3.50   9.5  0.10 0.000   0   3 -4068. -2217. -1851. -4262.   194. -76.9 -39.4   0.0 152.5 221.3 242.6   0.0  10.5  0.40
 19.4 -3.50   8.8  0.10 0.000   0   3 -4070. -2116. -1953. -4262.   192. -71.3 -34.8   0.0 143.3 207.9 228.0   0.0  10.5  0.40
 19.6 -3.50   8.1  0.10 0.000   0   3 -4071. -2007. -2064. -4262.   191. -65.6 -30.4   0.0 133.7 194.0 213.0   0.0  10.5  0.40
 19.8 -3.50   7.4  0.10 0.000   0   3 -4072. -1890. -2183. -4262.   189. -60.0 -26.1   0.0 123.9 179.7 197.4   0.0  10.5  0.40
 20.0 -3.50   6.7  0.10 0.000   0   3 -4074. -1763. -2310. -4262.   188. -54.3 -22.1   0.0 113.7 164.9 181.3   0.0  10.5  0.40
 20.2 -3.50   6.0  0.10 0.000   0   3 -4075. -1628. -2447. -4262.   187. -48.7 -18.3   0.0 103.2 149.7 164.7   0.0  10.5  0.41
 20.4 -3.50   5.3  0.10 0.000   0   3 -4076. -1483. -2592. -4262.   186. -43.0 -14.7   0.0  92.3 133.9 147.6   0.0  10.5  0.41
 20.6 -3.50   4.6  0.10 0.000   0   3 -4076. -1328. -2748. -4262.   186. -37.3 -11.4   0.0  81.1 117.7 129.9   0.0  10.5  0.41
 20.8 -3.50   3.9  0.10 0.000   0   4 -4077.     0. -4077. -4262.   185. -31.7   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.41
 21.0 -3.50   3.2  0.10 0.000   0   4 -4078.     0. -4078. -4262.   184. -26.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.41
 21.2 -3.50   2.5  0.10 0.000   0   4 -4078.     0. -4078. -4262.   184. -20.3   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.41
 21.4 -3.32   1.8  0.10 0.000   0   4 -3845.     0. -3855. -4049.   183. -13.9   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.41
 21.6 -2.62   1.2  0.10 0.000   0   4 -3013.     0. -3013. -3196.   183.  -7.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.41
 21.8 -1.92   0.7  0.10 0.000   0   4 -2161.     0. -2161. -2344.   183.  -2.9   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.41
 22.0 -1.22   0.3  0.10 0.000   0   4 -1309.     0. -1309. -1492.   183.  -0.9   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.41
 22.2 -0.52   0.1  0.10 0.000   0   4  -456.     0.  -456.  -639.   183.  -0.1   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.41
 22.4  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 22.6  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 22.8  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 23.0  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 23.2  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 23.4  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 23.6  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 23.8  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 24.0  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 24.2  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 24.4  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 24.6  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 24.8  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 25.0  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 25.2  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 25.4  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 25.6  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 25.8  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 26.0  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 26.2  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 26.4  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 26.6  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 26.8  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 27.0  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 27.2  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.42
 27.4  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.43
 27.6  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.43
 27.8  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.43
 28.0  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.43
 28.2  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.43
 28.4  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.43
 28.6  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.43
 28.8  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.43
 29.0  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.43
 29.2  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.43
 29.4  0.00   0.0  0.10 0.000   0   0     0.     0.     0.     0.     0.   0.0   0.0   0.0   0.0   0.0   0.0   0.0   7.2  0.43
```

CONTINUED ON NEXT PAGE

5.5) OUTPUT DATA FILE - FORO.3DAT - PARTIAL LISTING (CONT)

```
RUN SUMMARY:

TOTAL DISTANCE TRAVELLED:         S = 0.30 MI

TIME OF MISSION:               TMIN = 1.59 MIN

AVERAGE VEHICLE SPEED:         VAVE = 11.34 MPH

TOTAL ENERGY CONSUMED:         EVEH = 1.30 KW-HRS

SPECIFIC VEHICLE ENERGY:       ESPC = 4.33 KW-HRS/MI
```

5.6) COMMAND FILES - BUS3.CMD AND BUSL3.CMD

```
                         MAIN3.FOR
MAIN3.REL                ,PROF3.FOR
PROF3.REL                ,PCU3.FOR
PCU3.REL                 ,MOTOR3.FOR
MOTOR3.REL               ,FORO3.DAT
```

APPENDIX

GLOSSARY OF PROGRAM CONSTANTS AND VARIABLES

SYMBOL	DESCRIPTION	UNITS
ABAR	Average acceleration over TAU.	mph/sec
ACC	Vehicle acceleration rate.	mph/sec
ACC1	Previous value of ACC.	mph/sec
ACCM	Thrust limited acceleration.	mph/sec
AF	Vehicle frontal area.	ft^2
AJERK	Jerk rate.	mph/sec^2
AJERKR	Maximum jerk rate.	mph/sec^2
AMASS	Vehicle accelerating mass.	g-1b
AMP	Motor armature current.	amp
AMPF	Motor field current.	amp
AMPO	Current term in Froelich Equation.	amp
ARH	Rheostatic braking current.	amp
B, BB	Quadratic equation factors.	--
C, CC	Quadratic equation factors.	--
CAYPHI	Flux correction term in Froelich Equation.	--
CD	Aerodynamic drag coefficient.	--
CR	Rolling drag coefficient.	--
C2-C10	Motor loss term coefficients.	--
DECL	Vehicle deceleration rate.	mph/sec
DWELL	Dwell time at each stop.	sec
EA	Generated emf.	volt
EAO	Base value of EA.	volt
ESPC	Specific vehicle energy.	kw-hr/mi
EVEH	Vehicle input energy.	kw-hr
G(25,2)	Grade data array.	--
GEE	Acceleration due to gravity.	mph/sec

SYMBOL	DESCRIPTION	UNITS
GRADE	Roadway grade.	rad
HW	Encountered headwind.	mph
I,II	Stop indices.	---
IAC	Air conditioning status code.	---
ICC	Cam controller step index.	---
IDC	Driving cycle code.	---
IND	Operating mode index.	---
IND = 0	Vehicle at rest.	---
IND = 1	Motoring mode.	---
IND = 2	Regenerative braking mode.	---
IND = 3	Rheostatic braking mode.	---
IND = 4	Full friction braking mode.	---
INI	Initialization bypass code.	---
IOF	Output file selection code.	---
IREQ	Rheostatic braking control code.	---
ISW	Stopping logic control code.	---
IWC	Output write command code.	---
I1,I2	Output control codes.	---
JG	Grade index.	---
JM	Route length mile index.	---
KG	Grade index.	---
NP	Number of passengers.	---
NS	Number of stops per mile.	---
NT	Number of transits of route.	---
PAC	Air conditioning compressor power.	kw
PAIR	Average air compressor load.	kw

SYMBOL	DESCRIPTION	UNITS
PAUX	Auxiliary power load.	kw
PBAR	Average vehicle power over TAU.	kw
PBC	Average battery charger load.	kw
PCBLO	Air conditioning condensor blower.	kw
PCUL	Power conditioning unit loss.	kw
PECBLO	Environmental control blower.	kw
PHIR	Route direction.	deg
PHIW	Wind direction.	deg
PLTG	Lighting power.	kw
PS	Traction motor shaft power.	kw
PTMA	Traction motor armature power.	kw
PTMF	Traction motor field power.	kw
PVEH	Vehicle input power.	kw
PVEH1	Previous value of PVEH.	kw
PW	Propulsion power.	kw
P1	Air gap power.	kw
P2-P8	Traction motor power loss terms.	kw
P9	Drive train losses.	kw
R	Armature circuit resistance.	ohm
RA	Armature resistance.	ohm
RATIO	Reudction gear ratio.	--
RD	Dynamic braking resistance.	ohm
RF	Field resistance.	ohm
RFO	Minimum value of RF.	ohm
RPM	Traction motor speed.	rpm
RS	Armature circuit series resistance.	ohm

SYMBOL	DESCRIPTION	UNITS
RSO	Series resistance factor.	ohm
RSH	Shunt field resistance.	ohm
S	Distance traveled since start of run.	mi
SET	Armature current setpoint.	amp
SIGMA	Corrected turns ratio.	--
SIGMA1	Field/Armature turns ratio.	--
SN	Location of next stop.	mi
SR	Route length.	mi
SS	Distance between stops.	mi
STAB	Location of brake initiation point.	mi
TA	Aerodynamic drag.	lbf
TAU	Computing interval.	sec
TAU1	Factor for computing TAU.	sec
TAUMU	Time added at end of route.	sec
TD	Total drag force.	lbf
TE	Tractive effort of propulsion system.	lbf
TF	Tire factor.	rpm/mph
TG	Grade drag.	lbf
THETA	Time from start of run.	sec
TIM	Output time clock.	sec
TIMX	Output interval.	sec
TM	Mechanical (friction) braking force.	lbf
TN	Net accelerating force.	lbf
TNI	Jerk limited thrust increment.	lbf
TP	Tractive force.	lbf
TR	Rolling drag.	lbf

SYMBOL	DESCRIPTION	UNITS
TS	Stopping clock.	sec
T1	Time to completion of onset.	sec
T2	Time to completion of constant deceleration.	sec
T3	Time to completion of flair.	sec
T4	Time to completion of dwell.	sec
V	Vehicle speed.	mph
VAVE	Average vehicle speed over mission.	mph
VB	Brush voltage drop.	volt
VBAR	Average vehicle speed over TAU.	mph
VC	Cruise speed.	mph
VOLT	Trolley wire voltage.	volt
VT	Traction motor terminal voltage.	volt
WS	Wind speed.	mph
WT	Vehicle gross weight.	lbf
WTCRB	Vehicle curb weight.	lbf
WTP	Weight of typical passenger.	lbf
XB	Stopping distance.	mi

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